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HIGH-RATE AND DUAL-MEDIA FILTRATION STUDY IN A NORTHWESTERN OHIO WATER PLANT

Kenneth A. Dostal, et al

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

January 1966

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PROJECT REPORT

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Engineering Activities
Basic and Applied Sciences Program
Federal Water Pollution Control Administration
Cincinnati Water Research Laboratory

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U. S. Department of Health, Education, and Welfare
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In recent years increased interest has been shown by industrial and municipal water-plant managers and operators in various modifications of treatment plant design. These modifications include the reduction or elimination of flocculation and sedimentation, filtration rates in excess of 2 gallons per minute per square foot (gpm/sq ft), and alterations in filter media. To keep abreast of the influence these modifications might have on finished water quality, the Cincinnati Water Research Laboratory has been cooperating with various State Health Departments and water plants in conducting experiments and making observations. Two previous studies have been made: one on high-rate filtration at Gaffney, South Carolina,[1] water plant and the other on high-rate and dual-media filtration at Easley, South Carolina,[2] water plant.

The project reported here was carried out in northwestern Ohio from August 1963 to July 1964 in a 7.5 mgd water plant that ~~utilizes~~ the Maumee River as its raw water source. This plant differs from

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*This work was performed while the authors were members of the Division of Water Supply & Pollution Control, Public Health Service, Department of Health, Education, and Welfare.

the South Carolina plants in that it involves a raw water source with an appreciable algae load and utilizes a softening process. Our objective was to evaluate high-rate and dual-media filtration on an effluent from a softening process that might have a considerable amount of algae passing through it during certain periods of the year. Factors evaluated included the removal of particulate matter and algae by both full-scale and small experimental filters, and the influence of filtration rate and type of filter media on the quantity and quality of water produced. No attempt was made to monitor coliform removal since previous work[3,4] showed good correlation between the removal of coliform and virus and the removal of particulate matter.

WATER SOURCE AND QUALITY

During the past few years, several water plants that utilize the Maumee River as their raw water source have had difficulty during certain periods of the year in producing a water free of taste and odors. One of the more troublesome periods is during the winter months after the river has become ice-covered. To get some insight into the cause of the odor problems, and additional information on the raw water source for the water plant involved in this study, three sets of grab samples were taken from the river in February and March 1964. Six sampling stations were located on the Maumee River and one each on the tributary rivers, Tiffin and Auglaize (Figure 1). The first two sets of samples were taken on February 7 and 28 when the rivers were covered with ice, and the last

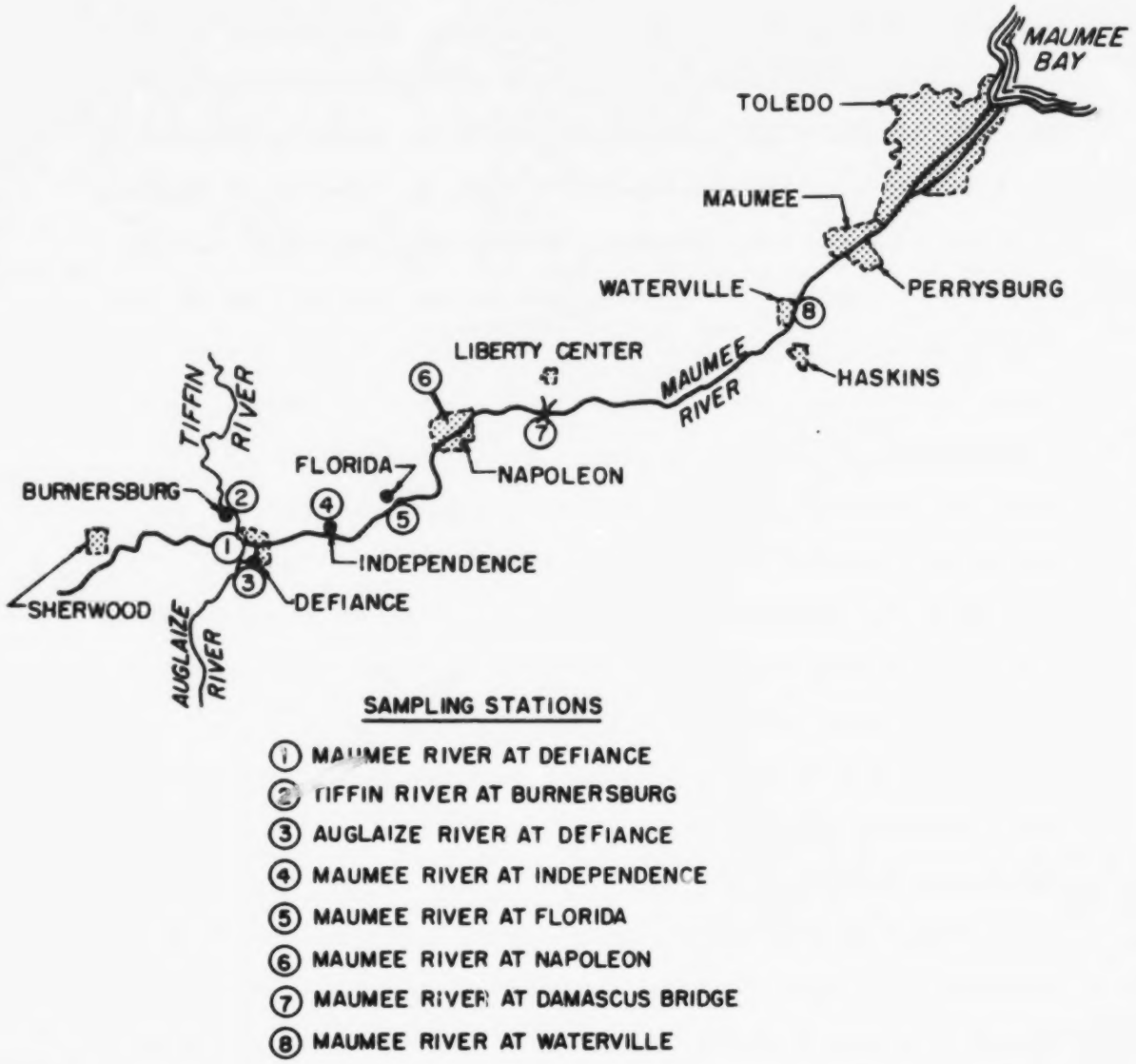

Figure 1. Location of sampling stations in Maumee River Basin.

set was taken March 19 after the spring breakup. All analyses were performed according to Standard Methods,[5] and the results are summarized in Tables 1, 2, and 3. The pollution present in the rivers is indicated by the following concentrations reported in Table 1: chloride, 58 mg/liter (stations 3 and 6); total phosphate, 4.7 mg/liter (station 3); ammonia nitrogen, 11.4 mg/liter (station 6); ABS, 0.5 mg/liter (station 6); and COD, 48 mg/liter (station 6). Samples taken on February 28 revealed similar levels of pollution. The last set of samples, however, showed a marked change in many of the parameters; the pH was lower and the alkalinity, hardness, chloride, phosphate, ammonia nitrogen, and ABS content were markedly reduced. This probably was due to increased dilution of the pollutional load. Color, COD, BOD, and organic nitrogen remained relatively constant, and the total suspended solids and nitrate nitrogen increased following the spring breakup.

The characteristics of the raw water entering the water-treatment plant during the test period are listed in Table 4.

DESCRIPTION OF WATER PLANT

Design capacity of the water plant is 7.5 mgd with a maximum throughput of 10 mgd. Softening is accomplished by a cold lime-soda process with up-flow sludge-blanket clarifiers, and ferric sulfate as a coagulant. Recarbonation is attained with carbon dioxide from the underwater gas burners. Sodium hexametaphosphate is added prior to filtration to prevent precipitation in the filters, which contain

TABLE 1. ANALYSES OF GRAB SAMPLES FROM MAUMEE RIVER ON FEBRUARY 7, 1964

Sample Station	pH	TSS, mg/l	Alkalinity, mg/l as $CaCO_3$	Total Hardness mg/l as $CaCO_3$	Color	Cl^- mg/l	Total $PO_4^{\equiv}$ mg/l	NO_3-N, mg/l	NH_4-N, mg/l	Organic N, mg/l	ABS, mg/l	BOD, mg/l	COD, mg/l
1	8.2	19	182	271	31	45	2.6	1.7	2.0	1.6	0.4	5	32
2	8.2	14	218	297	16	39	3.0	1.4	1.4	1.0	0.1	1	19
3	8.0	11	178	269	30	58	4.7	1.5	8.0	2.7	0.4	4	38
5	8.1	16	182	267	28	51	3.9	1.9	6.4	-	0.4	7	30
6	8.0	11	198	276	33	58	4.4	1.8	11.4	3.9	0.5	6	48

TABLE 2. ANALYSES OF GRAB SAMPLES FROM MAUMEE RIVER ON FEBRUARY 28, 1964

Sample Station	pH	TSS, mg/l	Alkalinity, mg/l as $CaCO_3$	Total Hardness mg/l as $CaCO_3$	Color	Cl^- mg/l	Total $PO_4^{\equiv}$ mg/l	NO_3-N, mg/l	NH_4-N, mg/l	Organic N, mg/l	ABS, mg/l	BOD, mg/l	COD, mg/l
1	8.6	8	213	330	20	79	4.5	1.8	1.2	1.7	0.5	4	27
2	8.1	8	259	360	9	51	4.0	0.4	0.8	1.3	0.2	4	21
3	8.3	8	225	330	16	63	4.5	1.5	1.5	2.1	0.5	5	31
4	8.2	11	221	322	16	55	4.5	1.8	1.9	4.1	0.5	6	31
5	8.6	58	206	330	19	60	3.3	1.6	2.5	2.5	0.5	5	35
6	8.3	9	205	313	17	57	4.3	1.7	3.4	1.9	0.5	4	31
7	8.2	5	197	306	22	59	4.3	1.8	5.3	2.2	0.4	4	29
8	8.4	16	217	304	16	63	4.5	1.6	8.5	2.0	0.4	10	44

TABLE 3. ANALYSES OF GRAB SAMPLES FROM MAUMEE RIVER ON MARCH 19, 1964

Sample Station	pH	TSS, mg/l	Alkalinity, mg/l as $CaCO_3$	Total Hardness mg/l as $CaCO_3$	Color	Cl^- mg/l	Total $PO_4^{\equiv}$ mg/l	NO_3-N, mg/l	NH_4-N, mg/l	Organic N, mg/l	ABS, mg/l	BOD, mg/l	COD, mg/l
1	7.8	112	90	205	55	20	1.0	7.8	0.2	2.3	0.1	3	36
2	8.2	33	162	314	14	38	0.7	6.3	0.3	1.8	0.1	3	27
3	7.8	57	84	199	41	20	0.8	8.4	0.4	2.2	0.1	2	31
4	7.9	87	94	203	48	21	1.0	7.5	0.2	2.1	0.1	3	35
5	7.9	97	84	193	45	18	0.9	8.4	0.3	2.3	0.1	3	35
6	7.9	119	87	202	58	19	1.0	8.2	0.4	2.4	0.1	3	37
7	7.8	111	84	194	50	19	1.0	7.8	0.3	2.4	0.1	3	39
8	7.8	145	91	186	45	18	0.9	7.7	0.3	2.5	0.1	3	41

TABLE 4. RAW-WATER CHARACTERISTICS AT WATER-TREATMENT PLANT

Characteristic	Range
River Flow, cfs	100 - 50,000
Turbidity, J.u.	< 20 - 1,200
Algae Count, no./ml	340 - 54,000
Temperature, °F	33 - 88
pH	7.6 - 8.7
Alkalinity, mg/l as $CaCO_3$	80 - 280
Hardness, mg/l as $CaCO_3$	150 - 400

24 inches of sand with an effective size (e.s.) of 0.45 mm and a uniformity coefficient (u.c.) of 1.9. The filters are provided with a surface wash that is used in the initial portion of the backwash cycle.

Prior to January 15, 1964, when pre-chlorination was provided, a dose of sodium hypochlorite was added, which resulted in a residual concentration of free chlorine of 0.1 mg/liter in the clarifiers. An amount was added also for post-chlorination so as to have 0.4 to 0.7 mg of free chlorine per liter of water leaving the plant. After January 15 only post-chlorination was provided.

TEST EQUIPMENT AND PROCEDURES

The experimental equipment consisted of two small dual-media filters plus auxiliary apparatus for continuous measurement of effluent turbidities and incremental head losses. Each of the filters contained 18 inches of coal (e.s. = 1.1 mm, u.c. = 1.2). Figure 2 shows details of a dual-media filter. The small filters obtained their influent from the same location as the full-scale filters. During certain runs either an additional coagulant or a filter aid was added to one or both of the small filters. These additions were made into a line connecting the constant-head box and the filter proper. One full-scale sand filter was also monitored continuously for total head loss and effluent turbidity.

RESULTS

Turbidity Removal

During the 1-year study, 28 runs were completed as well as several other investigations. The runs are summarized in Table 3 and are presented

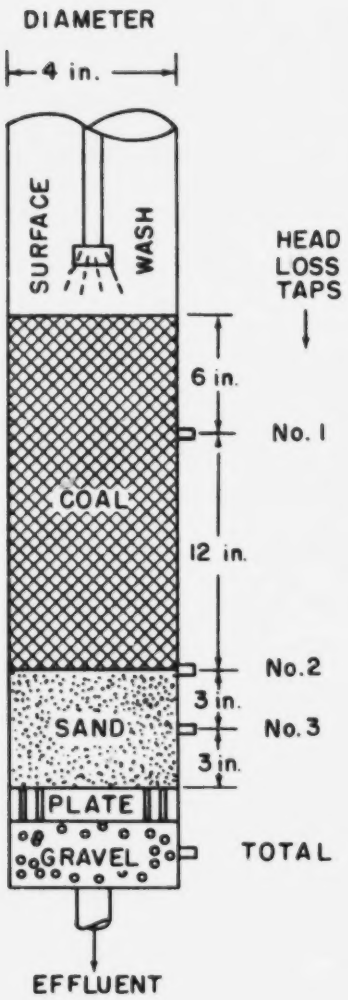

Figure 2. Details of dual-media filter.

TABLE 5. SUMMARY OF FILTER RUNS

Run No.	Date	Chemical[b] type	Dose, mg/l	Filter[a]	Rate gpm/sq ft	Influent turbidity,[c] J.u.	Final Head loss, ft	Effluent turbidity,[c] J.u.	Run length hr
1	8/29/63			SF 1	3	8	7.5	2	48
				SF 2	2	8	7.0	2.5	48
				LF	2.8	8	4.0	2.5	12
				LF	2.8	8	5.8	2.5	18
2	9/2/63			SF 1	3	11	5.2	3	49
		Aid	0.05	SF 2	3	11	7.5	3	49
				LF	2.8	11	5.7	3.5	21
				LF	2.8	11	6.4	2.5	24
3	9/11/63			SF 1	3	17	6.4	4	28
		Aid	0.1	SF 2	3	17	7.0	4	28
				LF	2.8	17	5.5	4.5	18
4	9/12/63	Aid	0.5	SF 1	3	24	4.7	2	38
				SF 2	3	24	7.8	2	36
				LF	2.8	24	6.4	2	22
5	9/16/63			SF 1	3	20	7.7	2	47
		Aid	1.0	SF 2	3	20	8.0	2	45
				LF	2.8	20	6.6	2	22
6	9/18/63	Aid	1.0	SF 1	6	31	4.1	9	9.5
				SF 2	6	31	4.5	9	9.5
				LF	2.8	31	1.6	9	8.5
7	9/19/63			SF 1	1	16	0.4	3	17
		Aid	0.5	SF 2	1	16	0.4	3	17
				LF	2.8	16	2.9	3	18

TABLE 5. (Cont'd.)

Run No.	Date	Chemical[b] type	Dose, mg/l	Filter[a]	Rate gpm/sq ft	Influent turbidity,[c] J.u.	Final Head loss, ft	Effluent turbidity,[c] J.u.	Run length, hr
8	9/20/63	Iron	25	SF 1	4	18	7.8	0.4	8
				SF 2	4	18	1.2	2.5	9
				LF	2.8	18	2.2	2.5	15
9	9/21/63	Alum	10	SF 1	4	18	2.4	0.4	20
		Aid	0.7	SF 2	4	18	1.5	0.9	20
				LF	2.8	18	0.9	1.0	25
10	9/23/63	Iron	10	SF 1	5	24	8.4	0.5	10.5
				SF 2	5	24	2.7	2.5	12
				LF	2.8	24	1.0	2.5	12.5
11	9/24/63			SF 1	5	29	7.6	3	21
		Alum	10	SF 2	5	29	7.5	3.5	20.5
				LF	2.8	29	1.9	3	19.5
12	9/25/63	Aid	0.5	SF 1	5	15	7.5	2.5	18
				SF 2	5	15	5.4	2.5	19
				LF	2.8	15	0.9	2.5	17
13	9/26/63			SF 1	6	19	3.4	3.5	9
		Iron	10	SF 2	6	19	8.0	0.7	6
				LF	2.8	19	1.8	3.5	13
14	9/27/63	Alum	10	SF 1	6	19	3.8	4	8
				SF 2	6	19	2.8	4	8
				LF	2.8	19	0.7	4	8.5
15	9/28/63			SF 1	3	20	1.7	2.5	19
		Iron	10	SF 2	3	20	6.6	0.4	19
				LF	2.8	20	7.2	2.5	19.5

TABLE 5. (Cont'd.)

Run No.	Date	Chemical[b] type	Dose, mg/l	Filter[a]	Rate gpm/sq ft	Influent turbidity,[c] J.u.	Final Head loss, ft	Effluent turbidity,[c] J.u.	Run length, hr
16	9/30/63	Iron	10	SF 1	2	12	5.6	0.5	21.5
				SF 2	2	12	1.0	2.5	21
				LF	2.8	12	6.5	2.5	21
17	10/1/63	Aid	0.5	SF 1	2	15	1.3	3.5	22
				SF 2	2	15	1.3	2.5	22
				LF	2.8	15	6.0	2.5	15
18	2/26/64	Iron	20	SF 2	2	9	2.1	1.0	13
		"	20	LF	2	9	4.2	0.6	11.5
19	2/27/64	"	10	SF 1	4	7	2.6	0.6	8
		"	10	SF 2	2	7	1.2	1.3	21.5
		"	10	LF	2	7	4.1	0.6	18
20	2/28/64	"	5	SF 1	2	6	1.3	0.4	23
		"	5	SF 2	4	6	3.1	0.6	23
		"	5	LF	2	6	6.0	0.5	23
21	3/17/64	"	10	SF 1	4	19	5.0	0.6	18
		"	10	SF 2	2	19	1.0	1.5	6
		"	10	LF	2	19	5.4	0.5	23
22	3/18/64	"	10	SF 1	4	20	4.5	0.4	18
		"	10	SF 2	2	20	3.5	0.5	38
		"	10	LF	2	20	6.8	0.4	26
23	3/19/64	"	10	SF 1	6	19	5.5	1.5	12
		"	10	LF	4	19	6.6	1	13

TABLE 5. (Cont'd.)

Run No.	Date	Chemical[b] type	Dose, mg/l	Filter[a]	Rate gpm/sq ft	Influent turbidity,[c] J.u.	Final Head loss, ft	Effluent turbidity,[c] J.u.	Run length, hr
24	7/21/64			SF 1	4	7	3.0	0.8	36
		Aid	0.2	SF 2	2	7	4.0	0.8	65
				LF	2	7	6.5	0.5	45
25	7/27/64	Iron	10	SF 1	4	5	7.2	0.8	18
		"	10	SF 2	6	5	7.2	0.8	14.5
				LF	2	5	1.0	> 2	9
26	7/28/64	"	5	SF 1	4	10	7.9	0.9	21.5
		"	5	SF 2	6	10	7.7	1.1	18
				LF	2	10	5.6	3	22.5
27	7/29/64	"	20	SF 1	4	7	7.6	0.3	15
		"	20	SF 2	6	7	7.2	0.3	8.5
				LF	2	7	1.6	2	19
28	7/30/64	"	15	SF 1	4	5	7.6	0.2	15
		"	15	SF 2	6	5	6.9	0.3	9.5
				LF	2	5	1.3	1.5	16

(a) SF = small dual-media filter
LF = full-scale sand filter

(b) Aid - Purifloc
Iron - Ferric Sulfate [$Fe_2(SO_4)_3 \cdot 9H_2O$]
Alum - [$Al_2(SO_4)_3 \cdot 14\ H_2O$]

(c) Averages

graphically in Figures 3 through 33. During September 1963, the first series of 17 runs (Figures 3 through 22) was conducted. These runs were made when the water plant was operated at or above design capacity to compare the full-scale and the small experimental dual-media filters and to check the feasibility of using a filter aid to improve removal of turbidity during troublesome periods. A comparison of the effluent turbidities of the full-scale filter operated at 2.8 gpm/sq ft with those of the small filter that had received no additional chemicals and was operated at filtration rates from 1 to 6 gpm/sq ft revealed no significant difference due to media type or filtration rate. Both filters produced water with an average effluent turbidity ranging from 2 (Run 4, Figure 6) to 9 Jackson units (J.u.), (Run 6, Figure 8); the overall average was about 3 J.u.

In this study the filter influent turbidity was not measured continuously. During special investigations, however, it was followed fairly closely, and good correlation was found between the changes in filter influent and effluent turbidity when no additional chemicals were added to filter influent.

In 9 of the 17 runs, a synthetic polyelectrolyte(Purifloc,* a product of Dow Chemical Co., Midland, Michigan) in doses of from 0.05 to 1.0 mg/liter was added as a filter aid to one of the small filters in an attempt to strengthen the floc. The filter runs in which the

* Mention of commercial products does not imply endorsement by the Department of Health, Education, and Welfare.

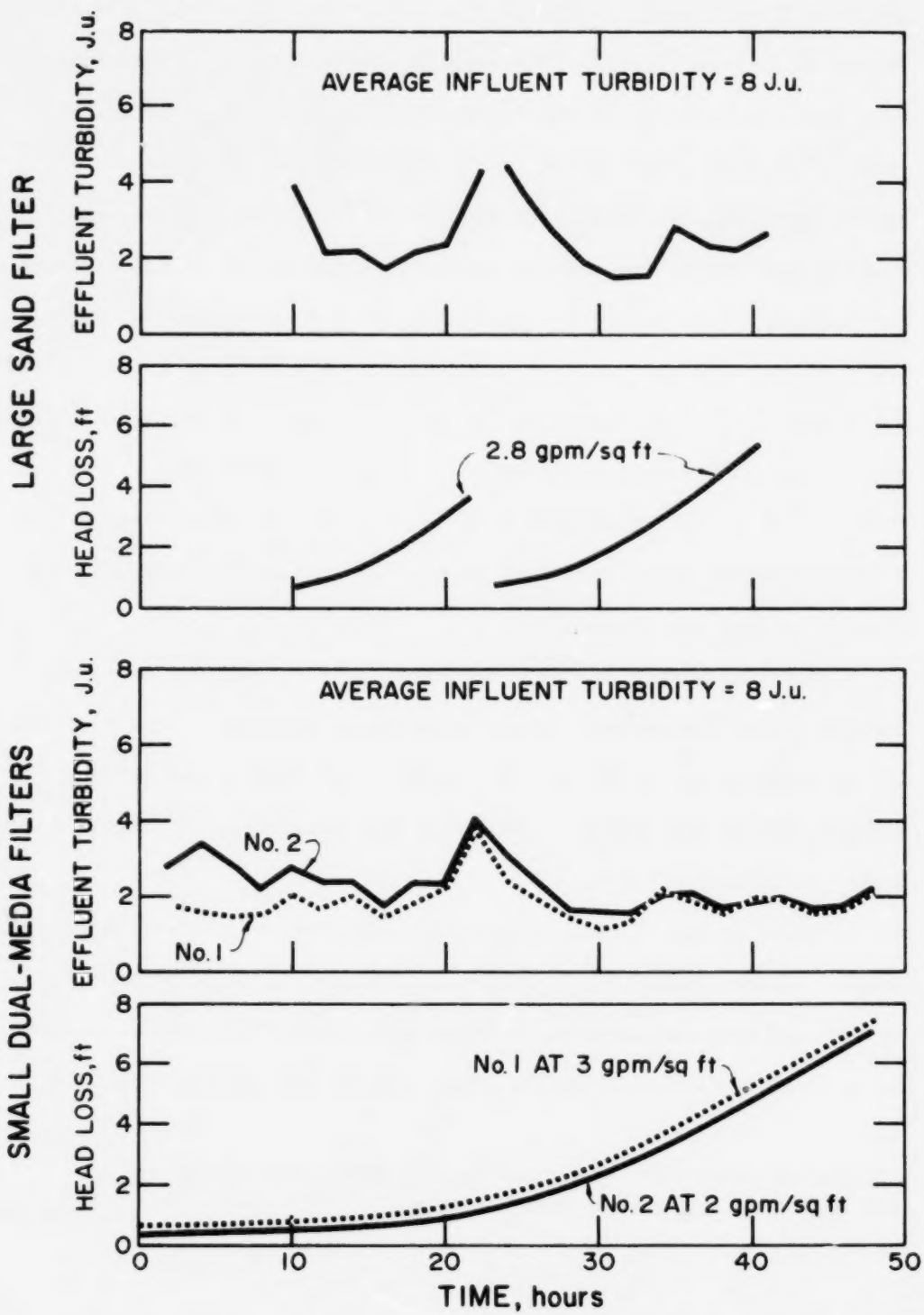

Figure 3. Head loss and turbidity values for Run 1, Aug. 29, 1963.

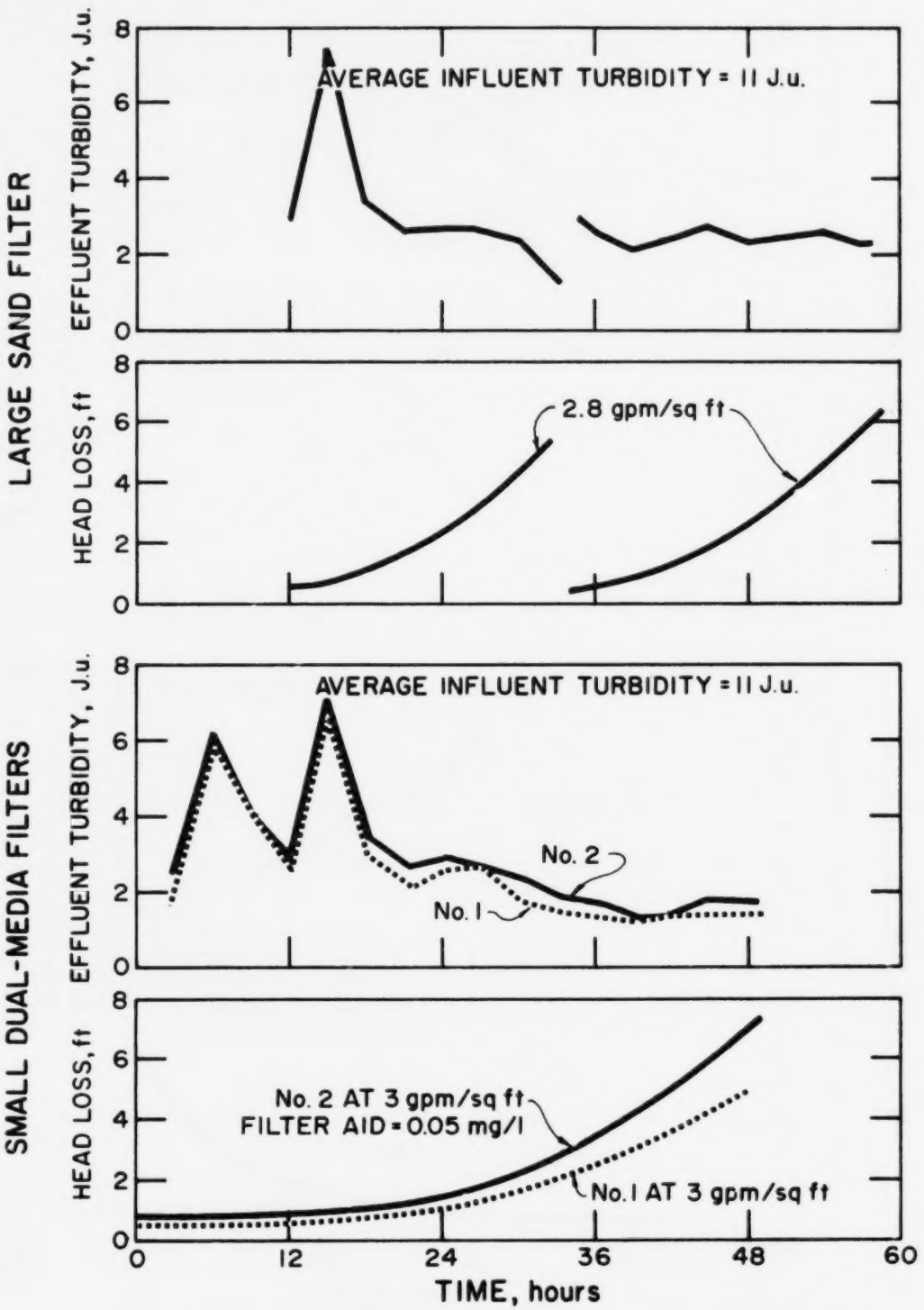

Figure 4. Head loss and turbidity values for Run 2, Sept. 2, 1963.

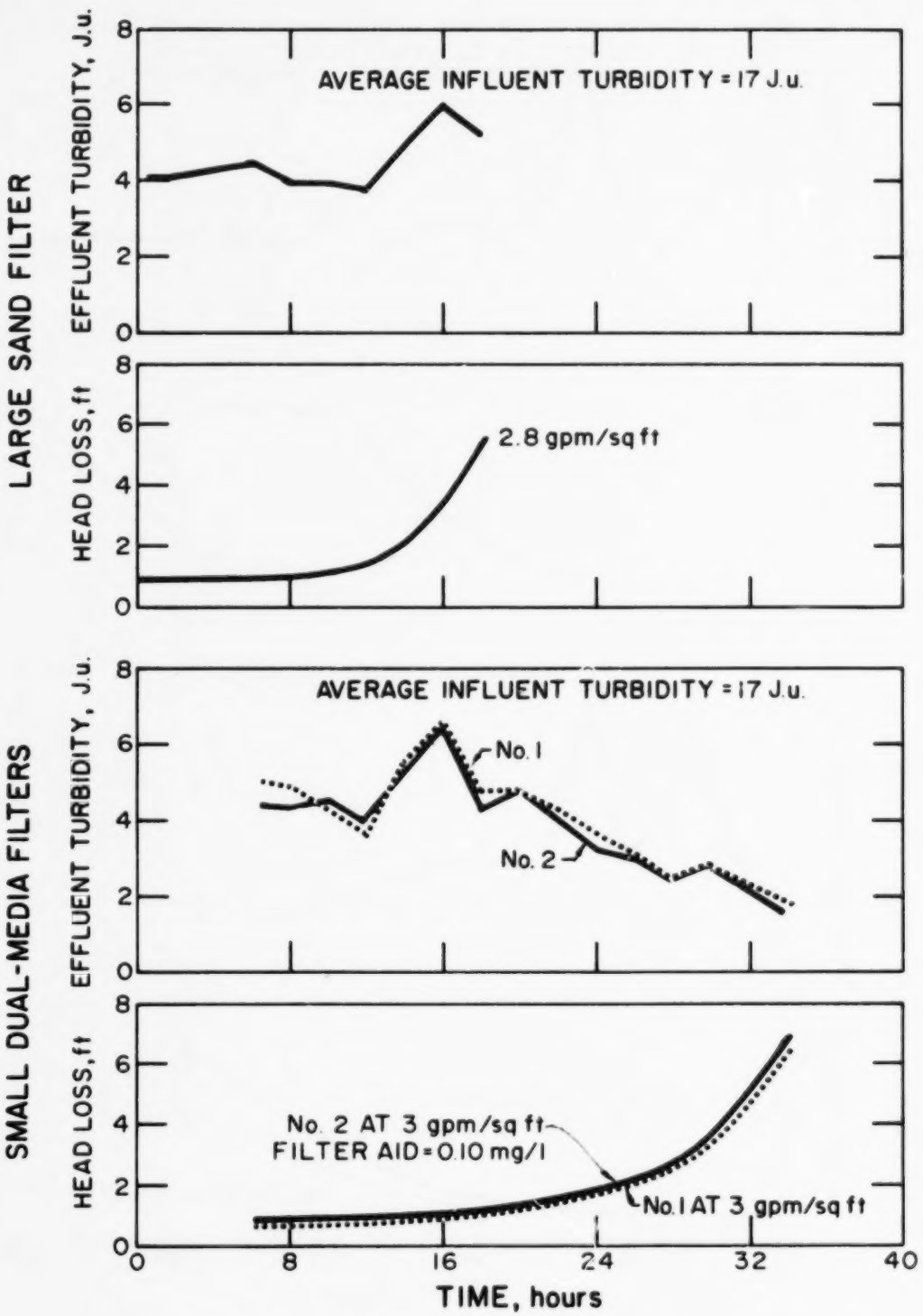

Figure 5. Head loss and turbidity values for Run 3, Sept. 11, 1963.

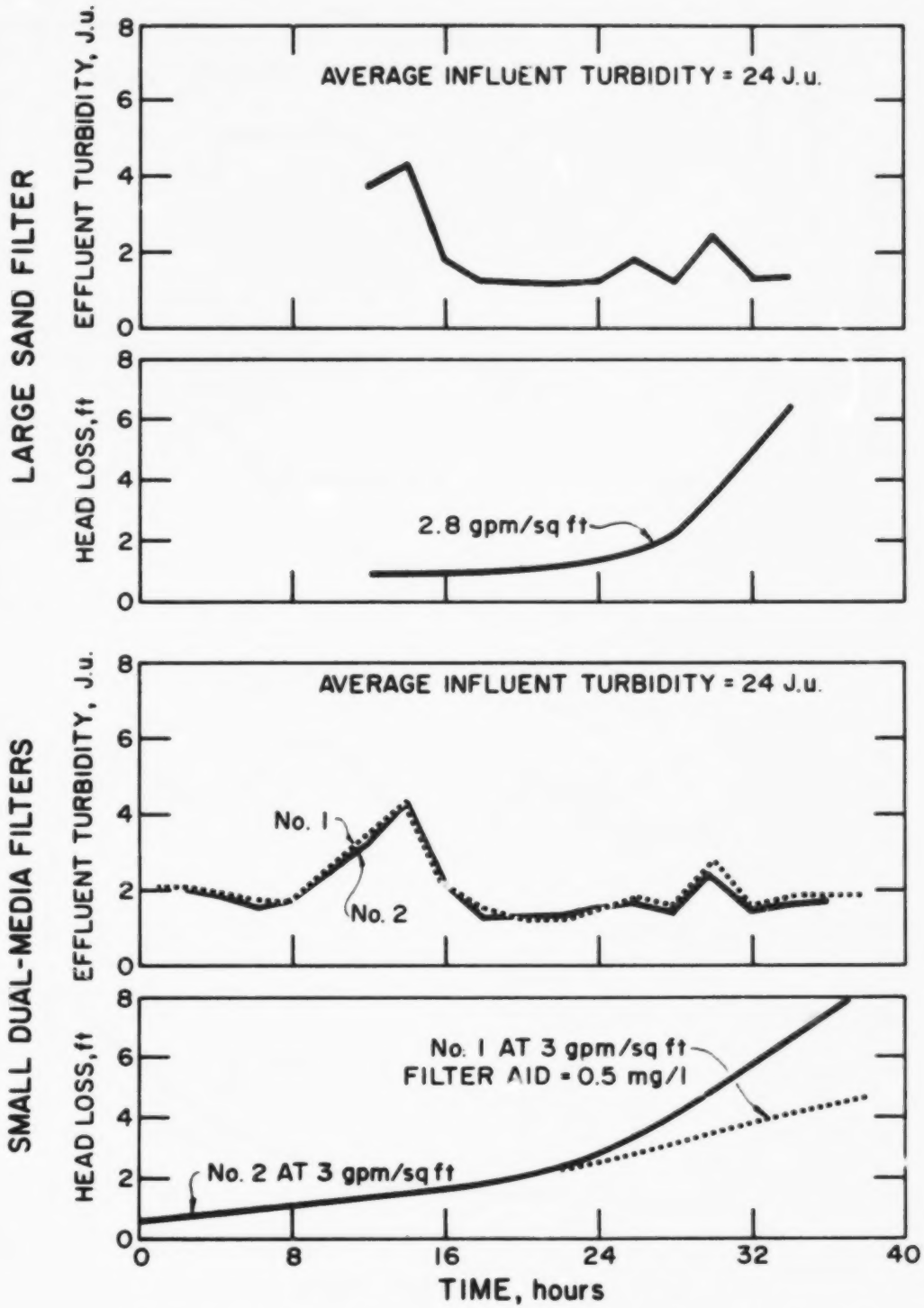

Figure 6. Head loss and turbidity values for Run 4, Sept. 12, 1963.

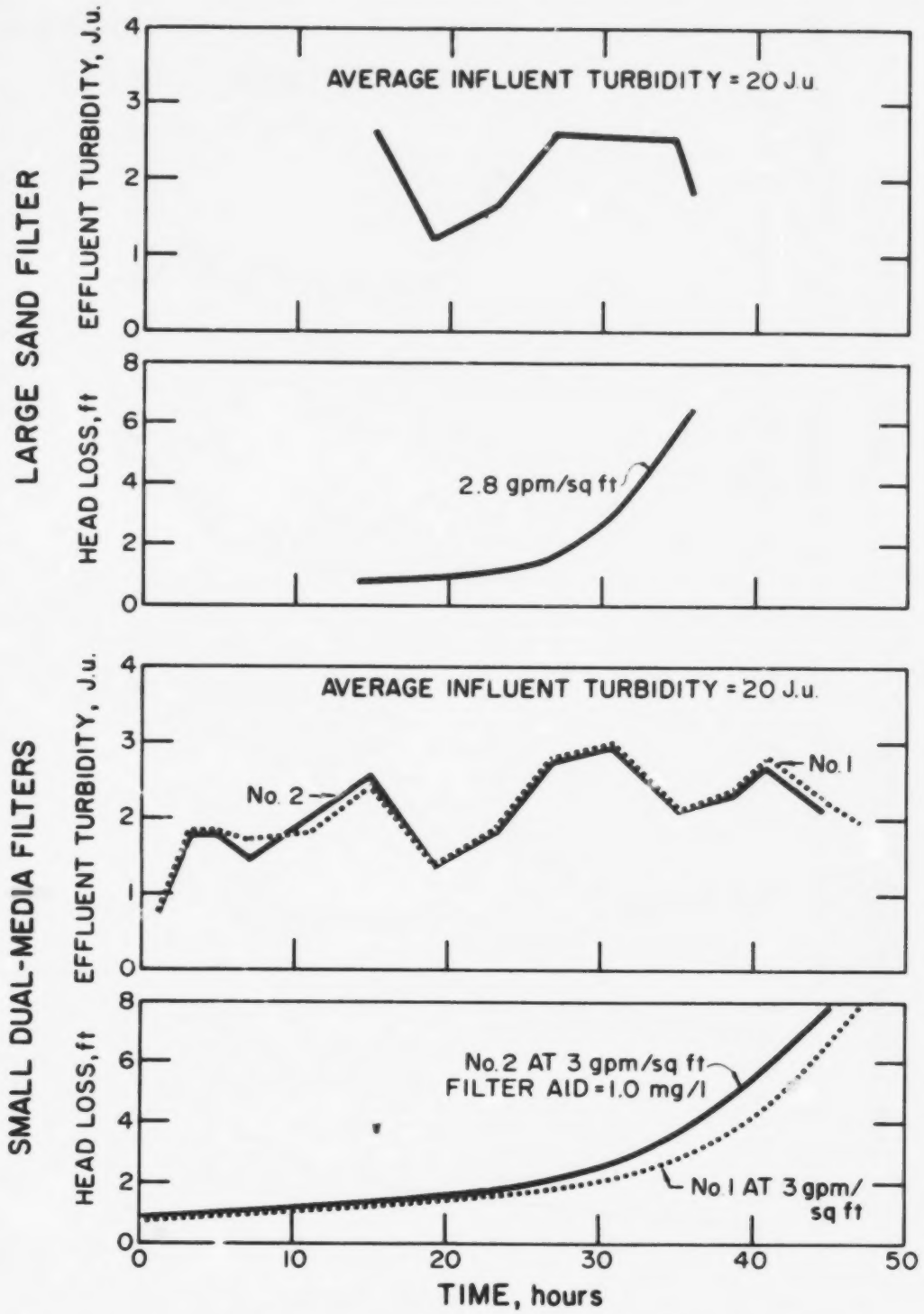

Figure 7. Head loss and turbidity values for Run 5, Sept. 16, 1963.

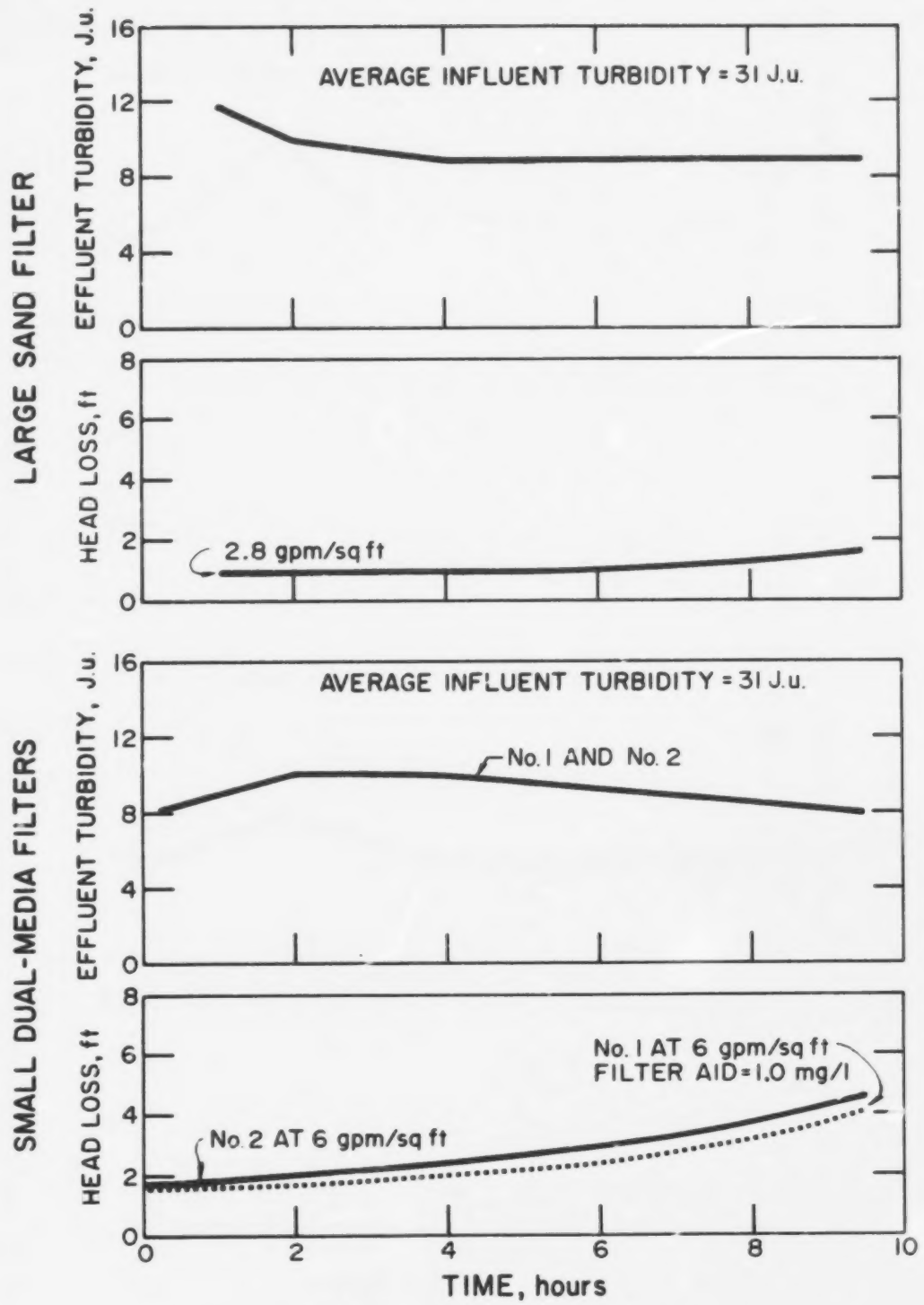
LARGE SAND FILTER
SMALL DUAL-MEDIA FILTERS
EFFLUENT TURBIDITY, J.u.
HEAD LOSS, ft
AVERAGE INFLUENT TURBIDITY = 31 J.u.
2.8 gpm/sq ft
No. 1 AND No. 2
No. 1 AT 6 gpm/sq ft
FILTER AID = 1.0 mg/l
No. 2 AT 6 gpm/sq ft
TIME, hours

Figure 8. Head loss and turbidity values for Run 6, Sept. 18, 1963.

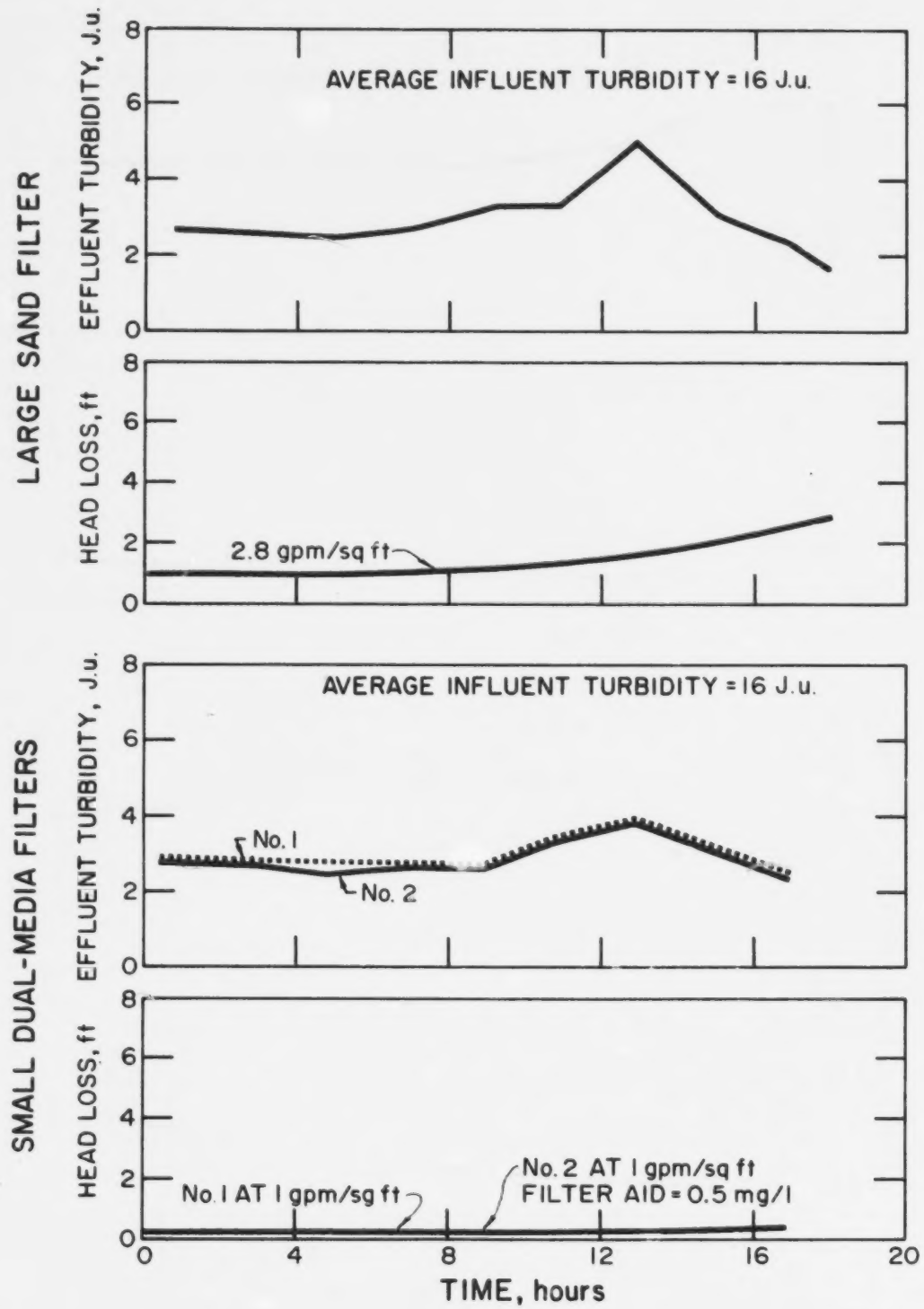

Figure 9. Head loss and turbidity values for Run 7, Sept.19, 1963.

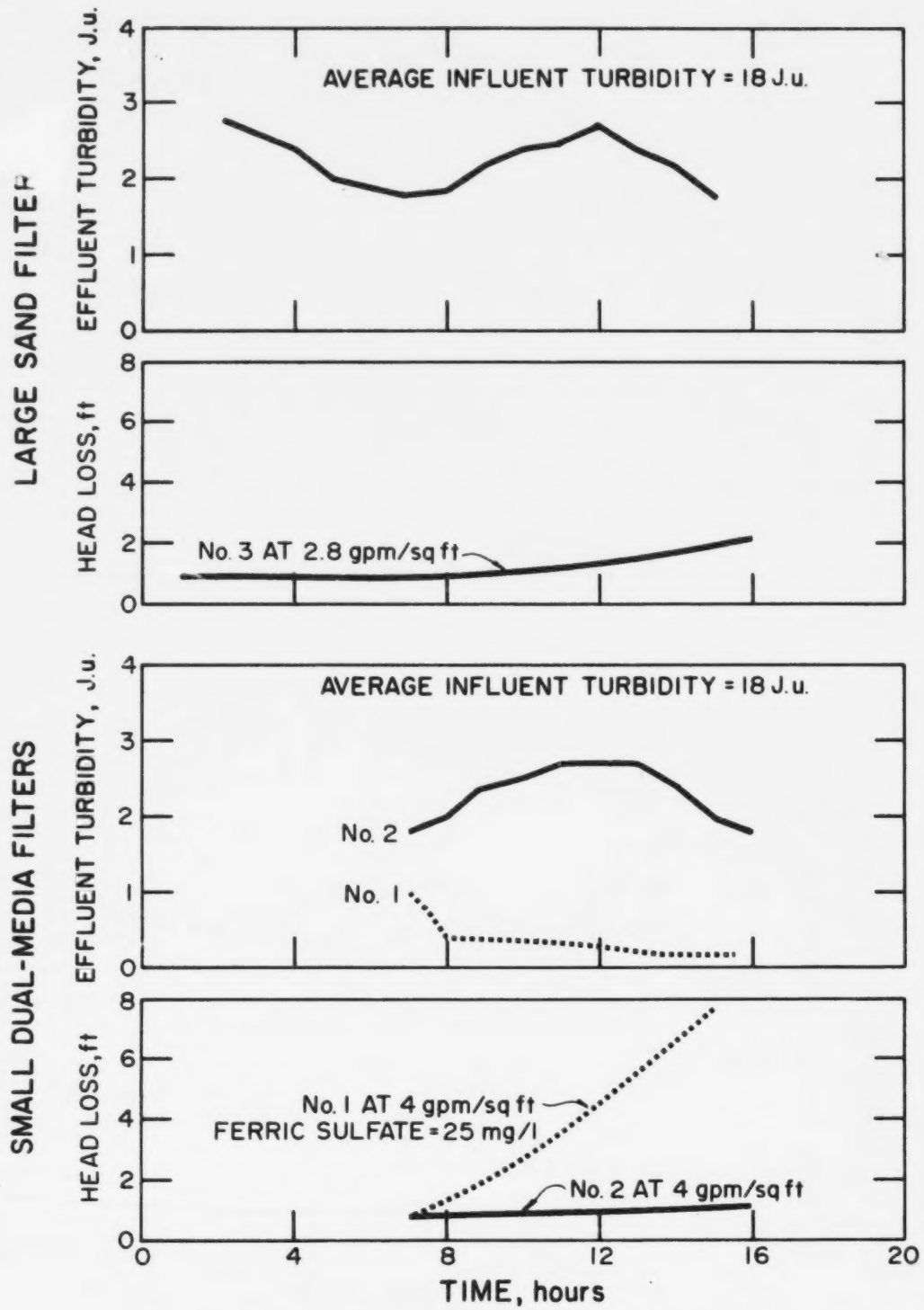

Figure 10. Head loss and turbidity values for Run 8, Sept. 20, 1963.

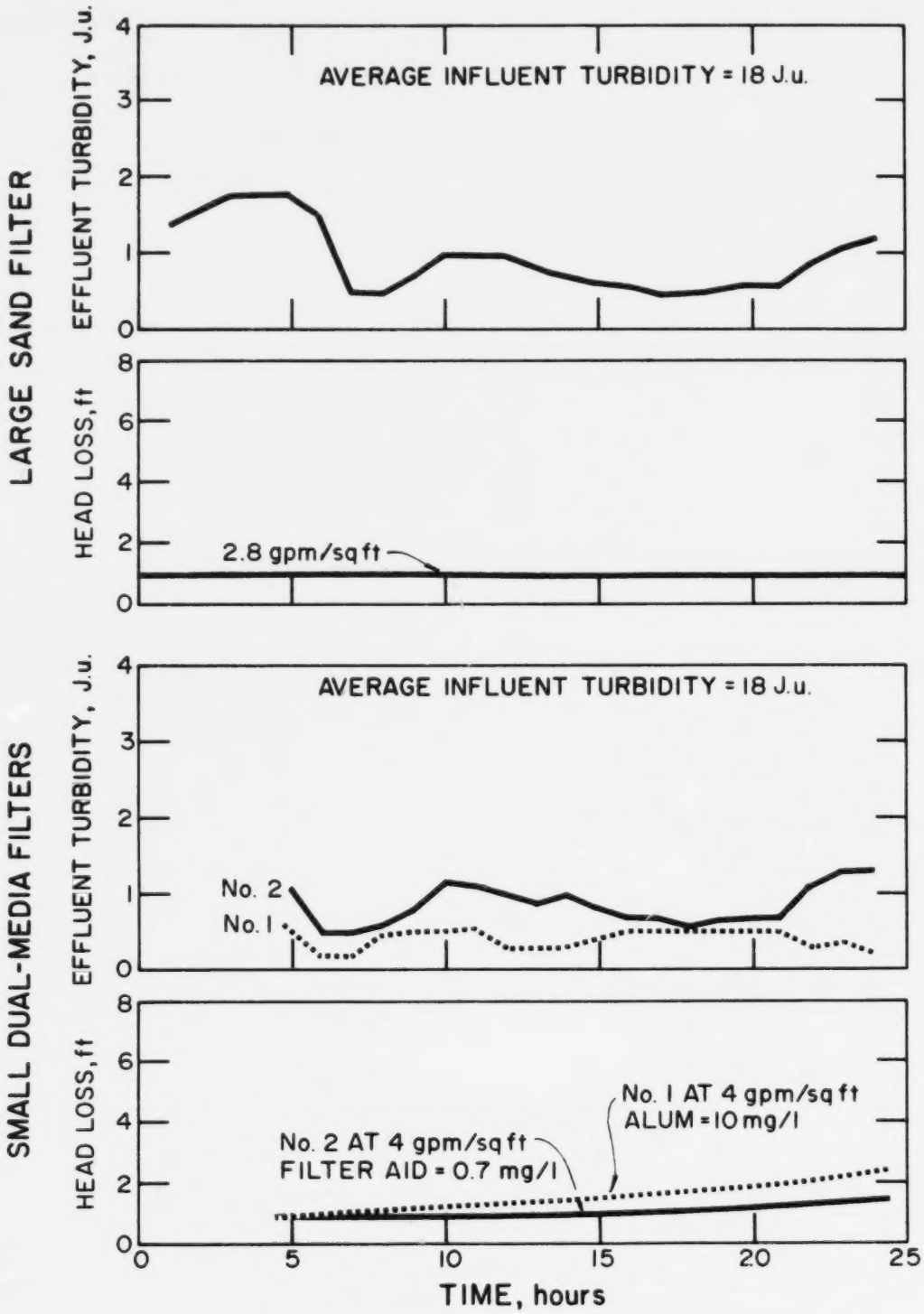

Figure 11. Head loss and turbidity values for Run 9, Sept. 21, 1963

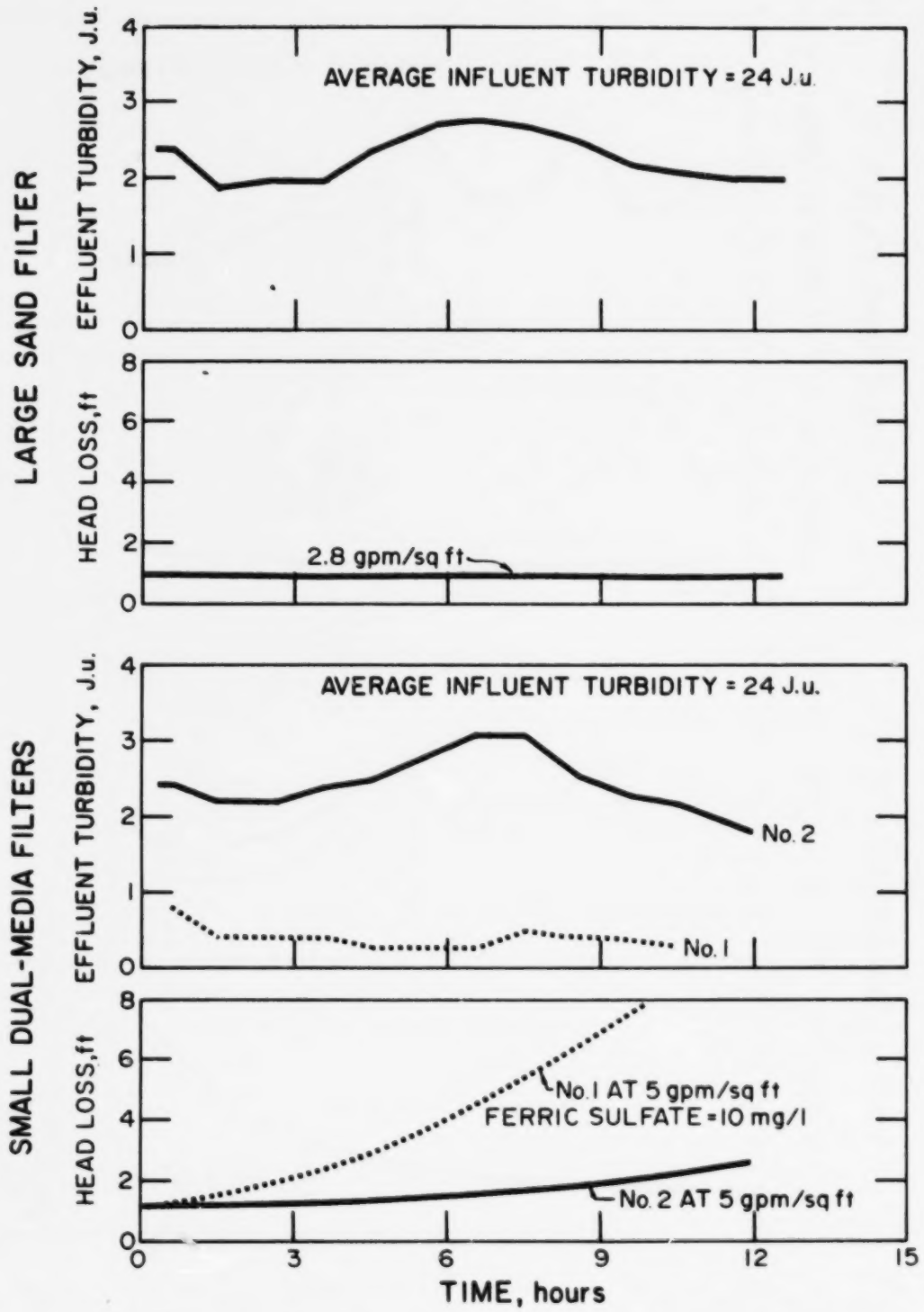

Figure 12. Head loss and turbidity values for Run 10, Sept. 23, 1963.

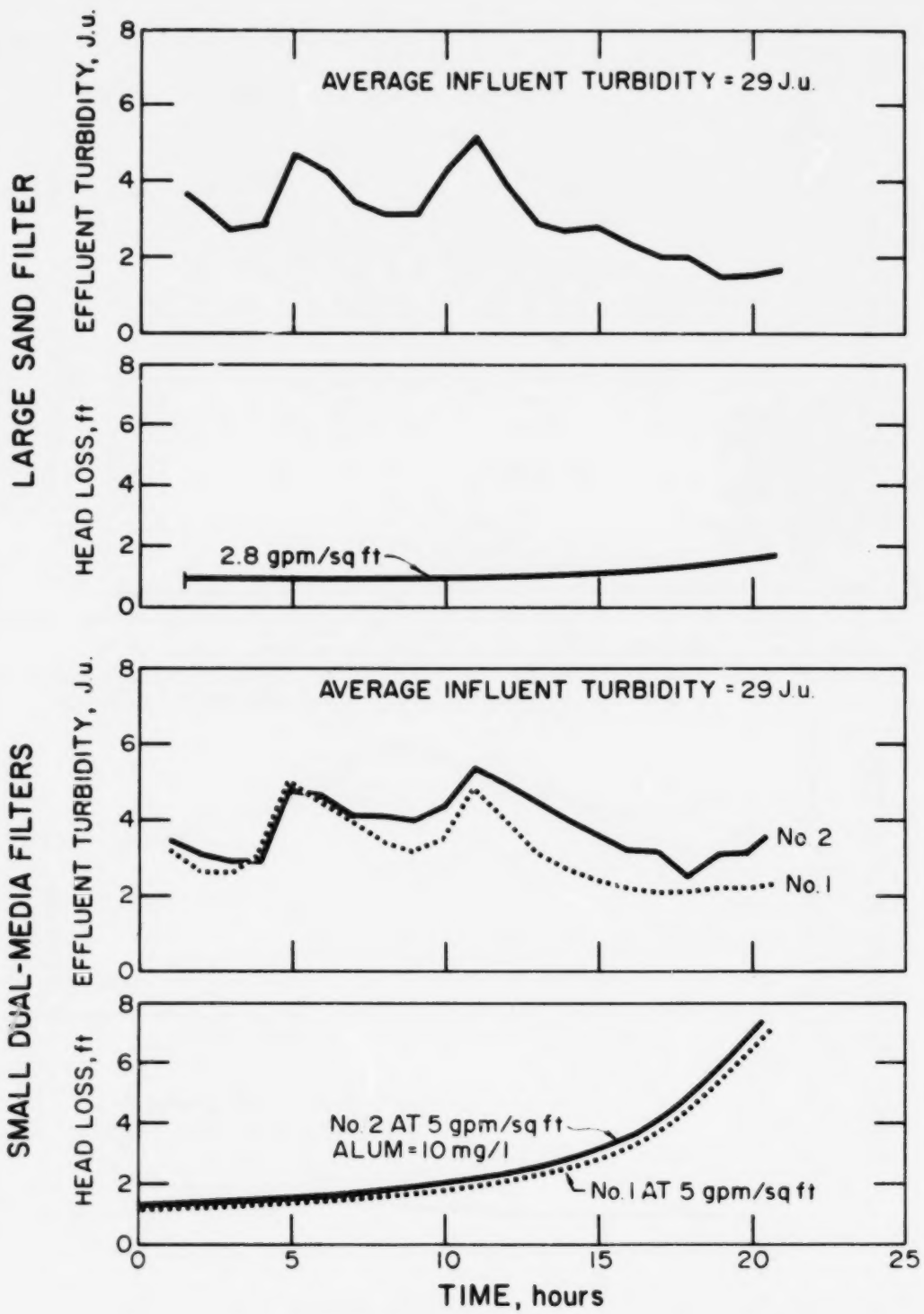

Figure 13. Head loss and turbidity values for Run 11, Sept. 24, 1963.

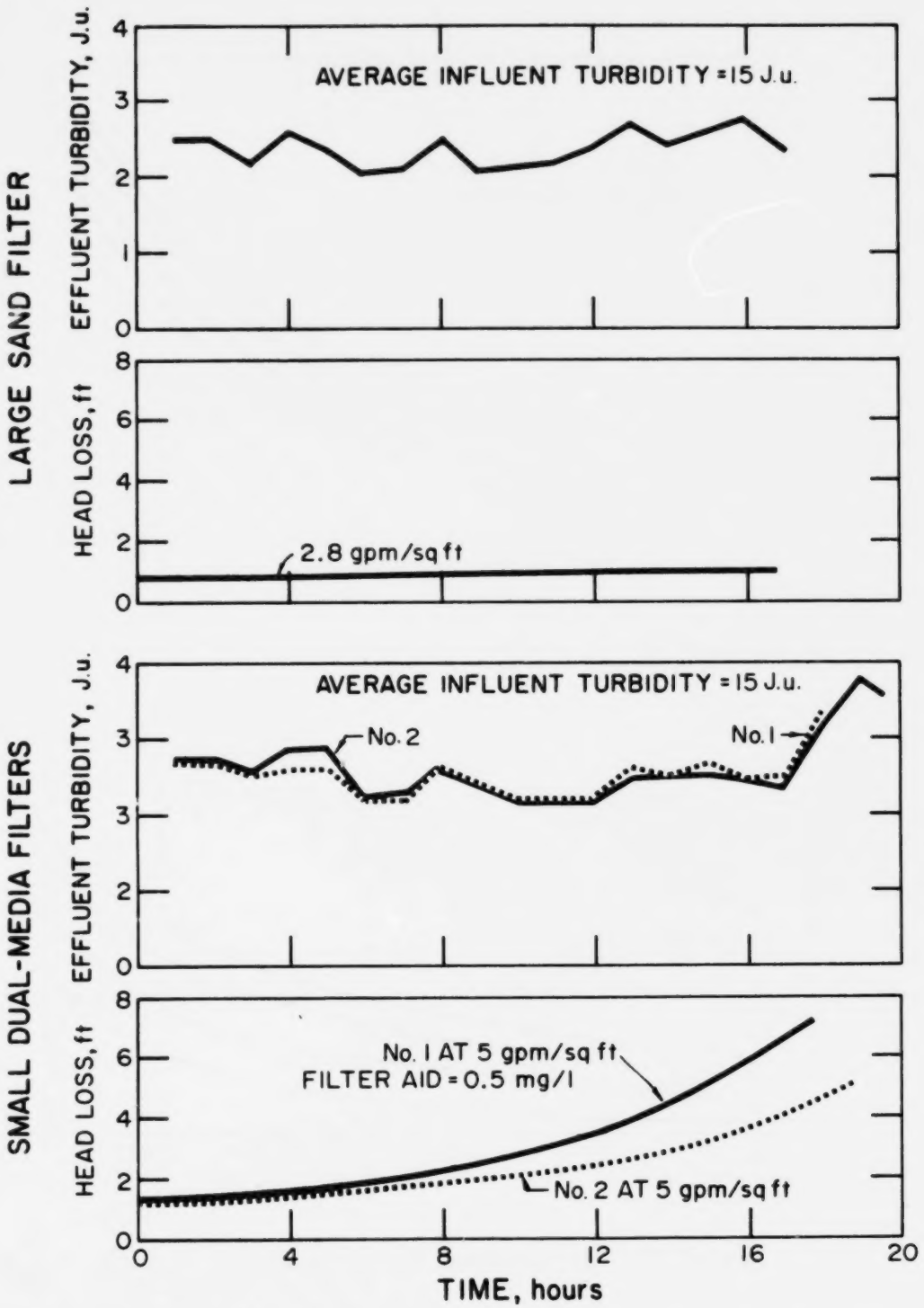

Figure 14. Head loss and turbidity values for Run 12, Sept. 25, 1963.

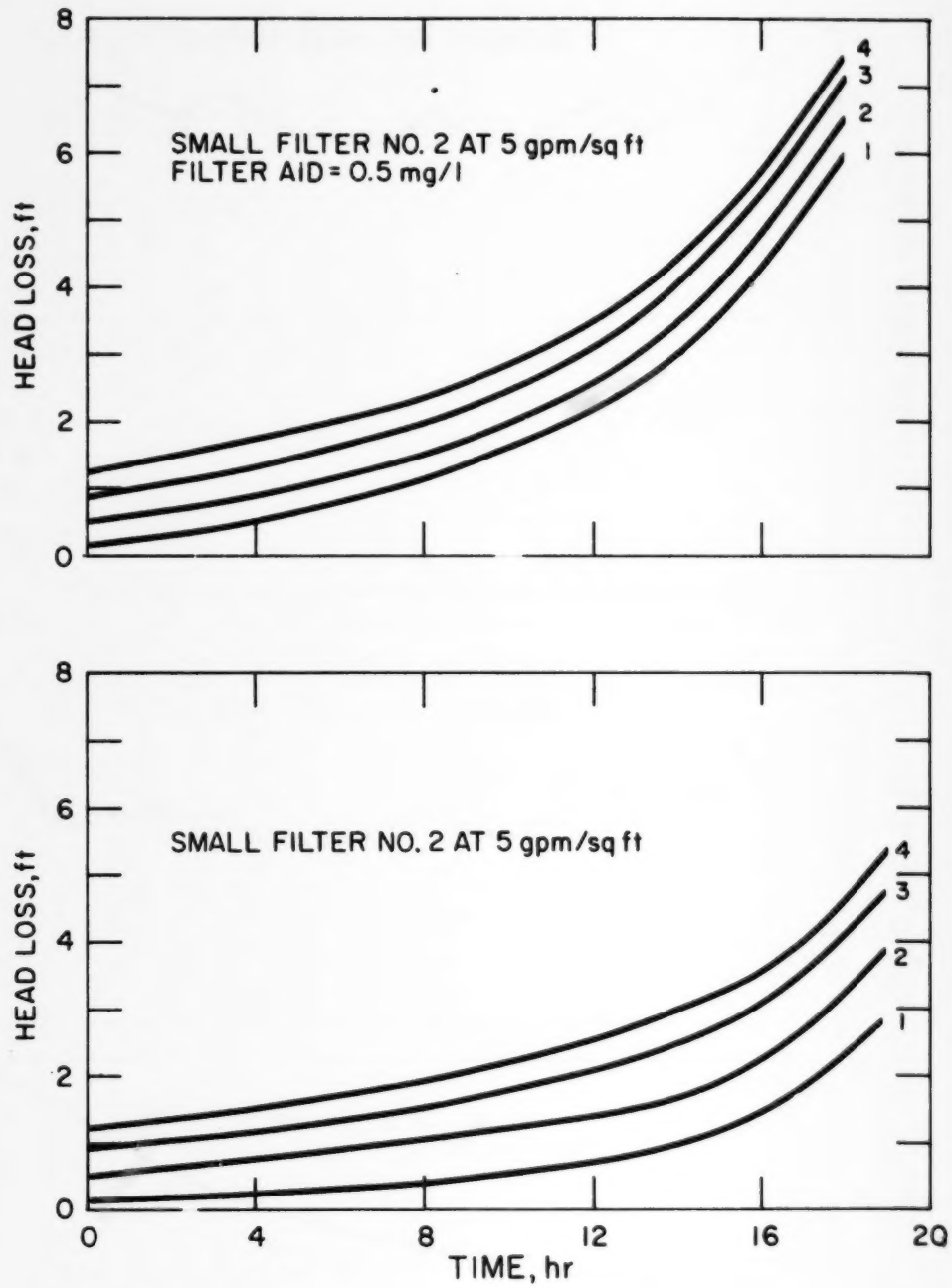

Figure 15. Incremental head losses for Run 12.

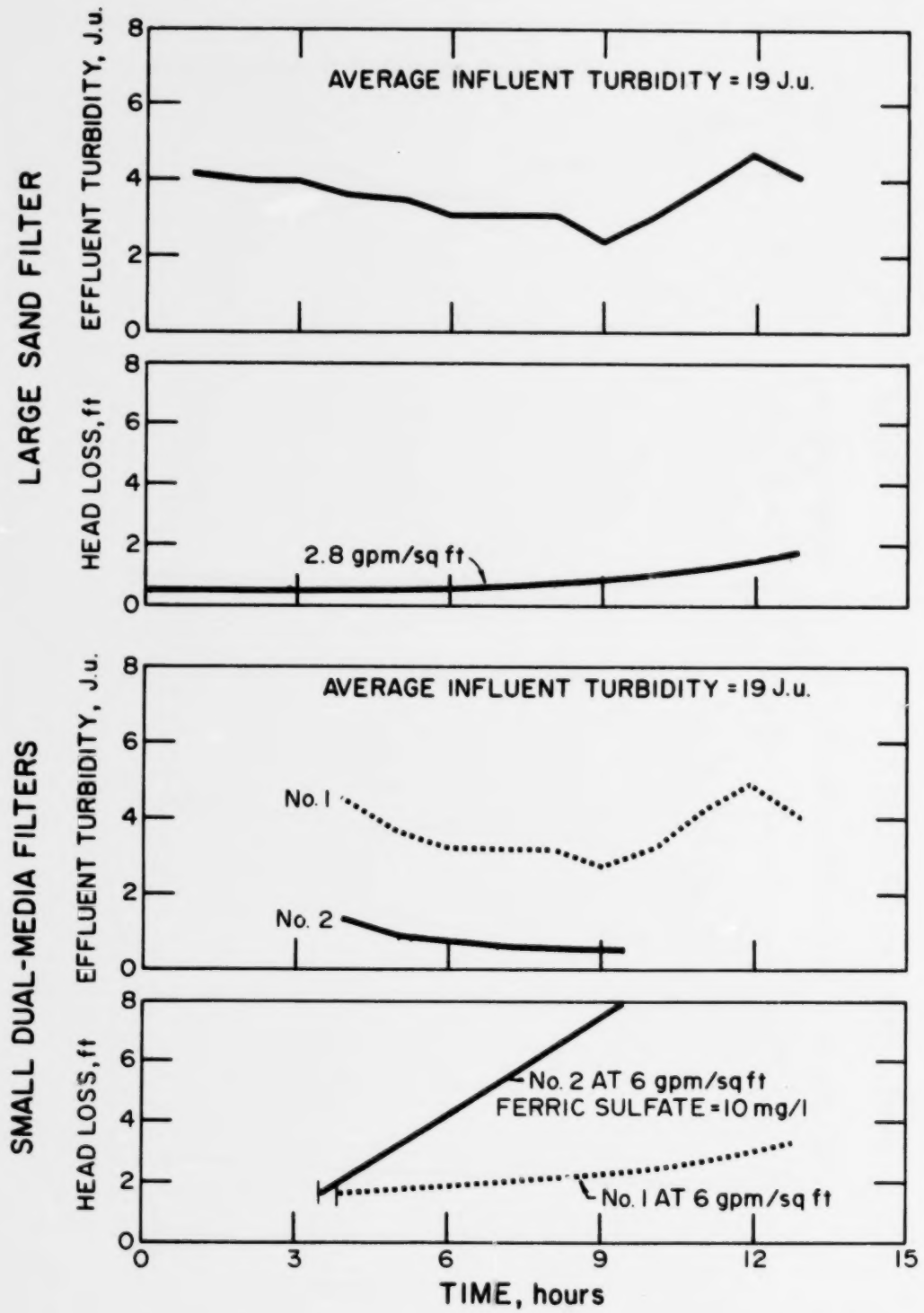

Figure 16. Head loss and turbidity values for Run 13, Sept. 26, 1963.

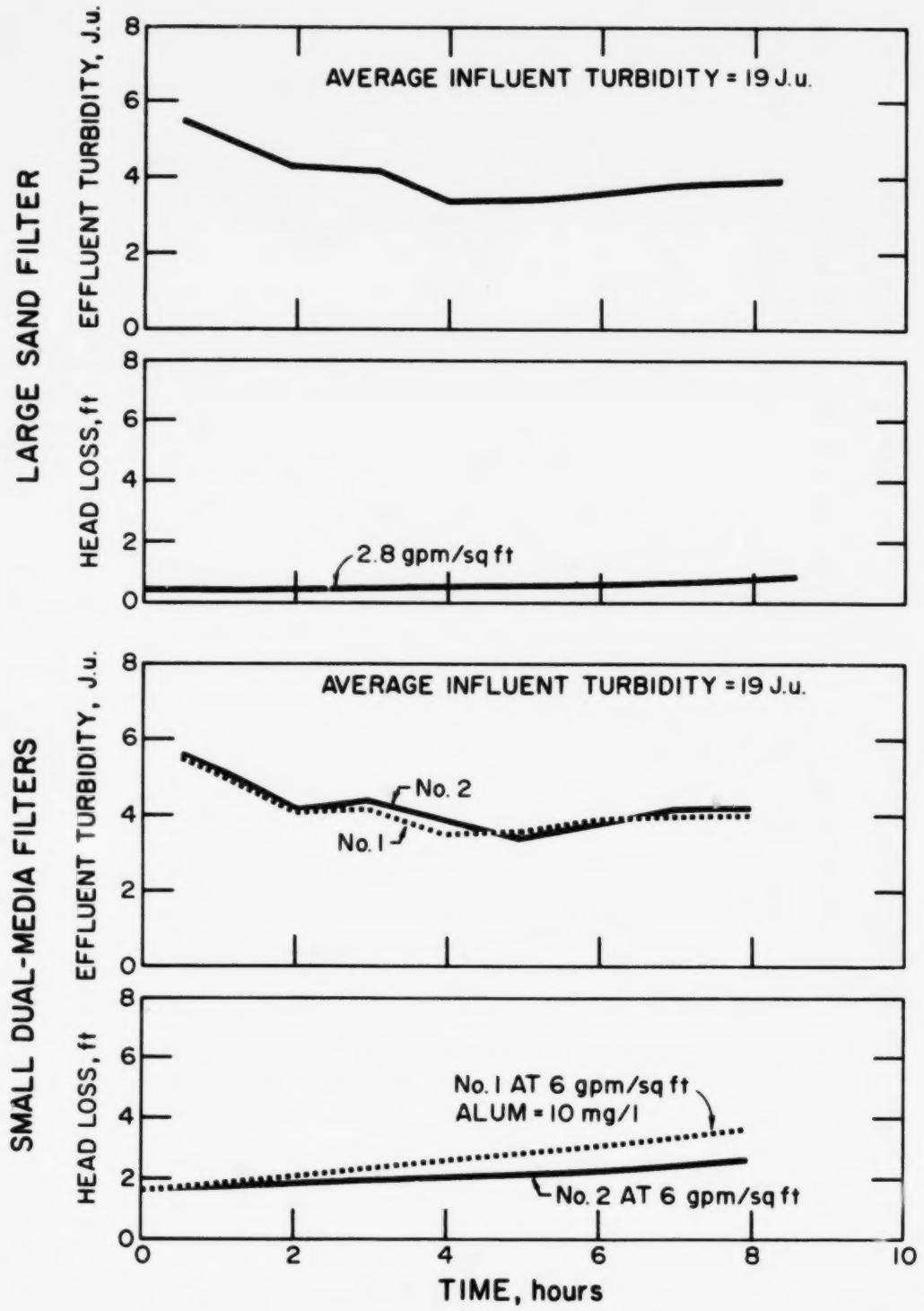

Figure 17. Head loss and turbidity values for Run 14, Sept. 27, 1963.

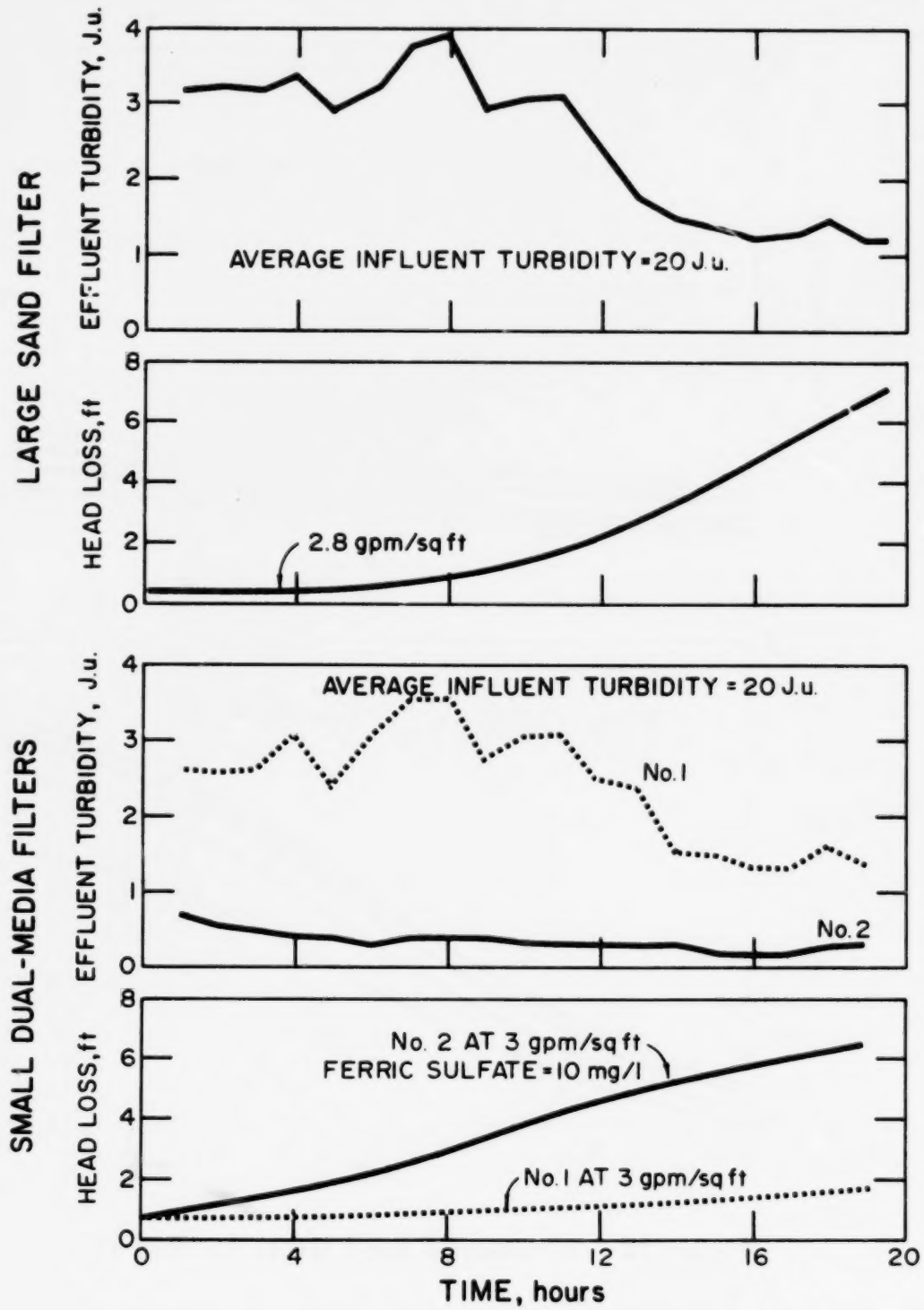

Figure 18. Head loss and turbidity values for Run 15, Sept. 28, 1963.

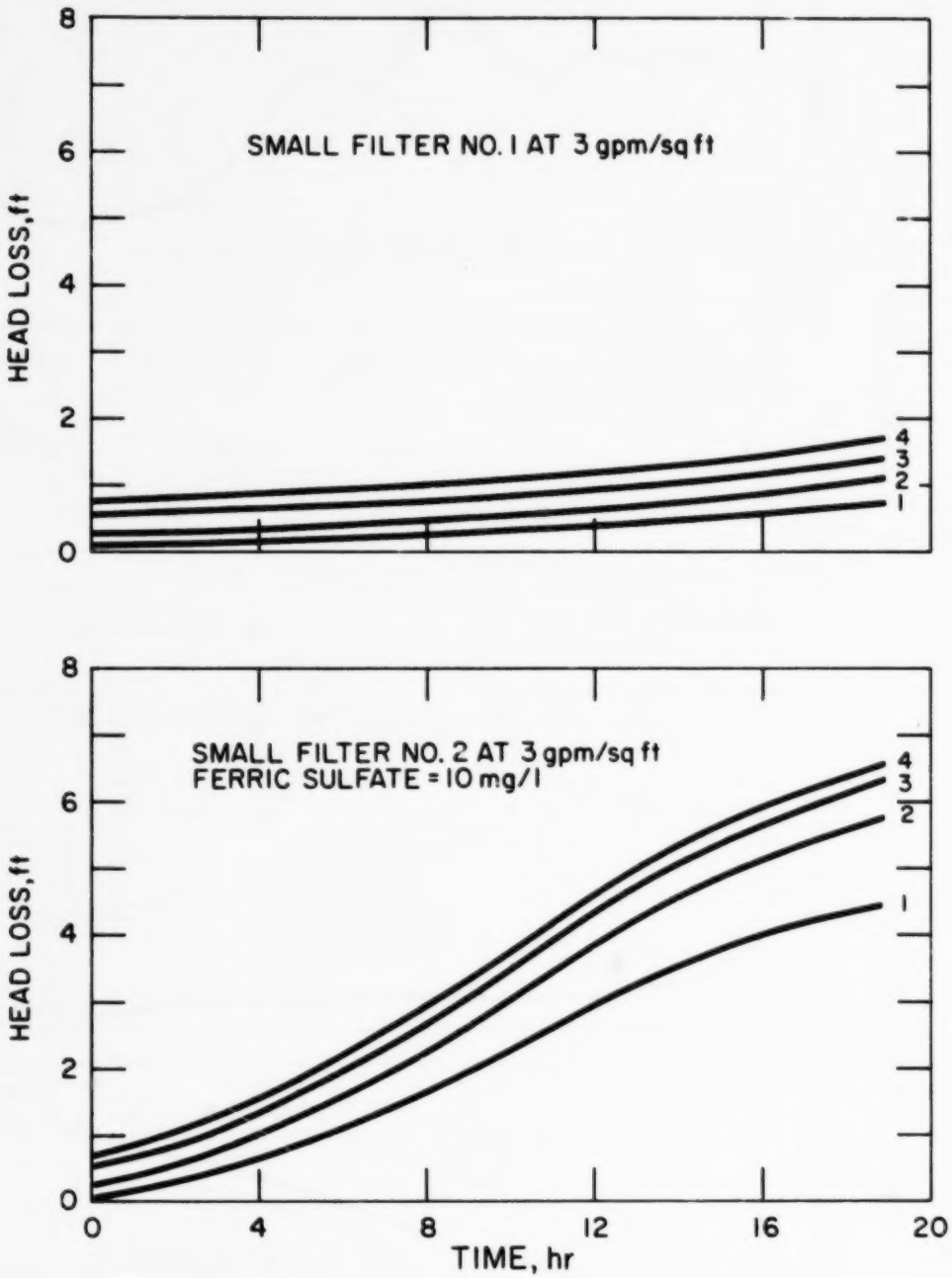

Figure 19. Incremental head losses for Run 15.

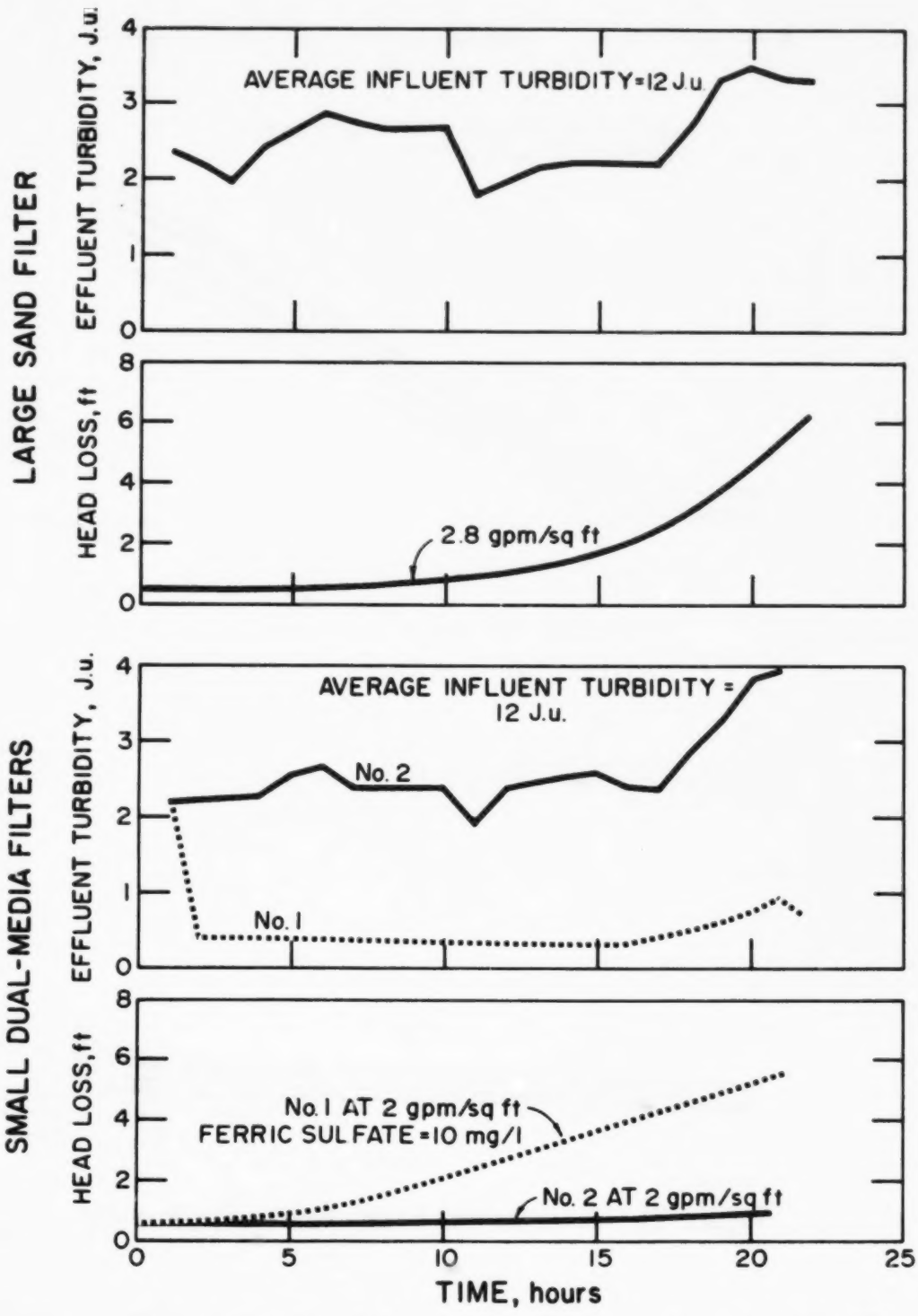

Figure 20. Head loss and turbidity values for Run 16, Sept. 30, 1963.

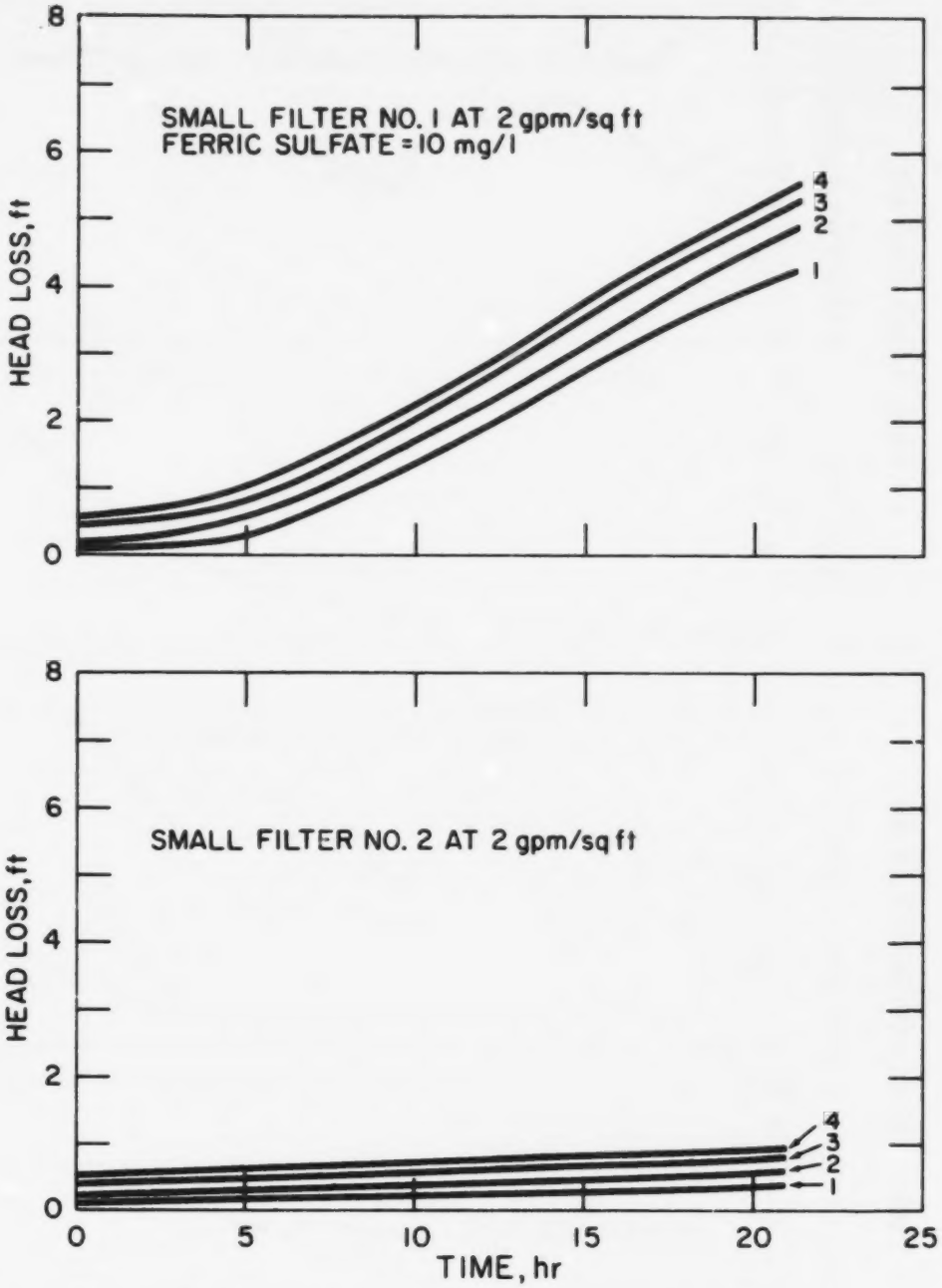

Figure 21. Incremental head losses for Run 16.

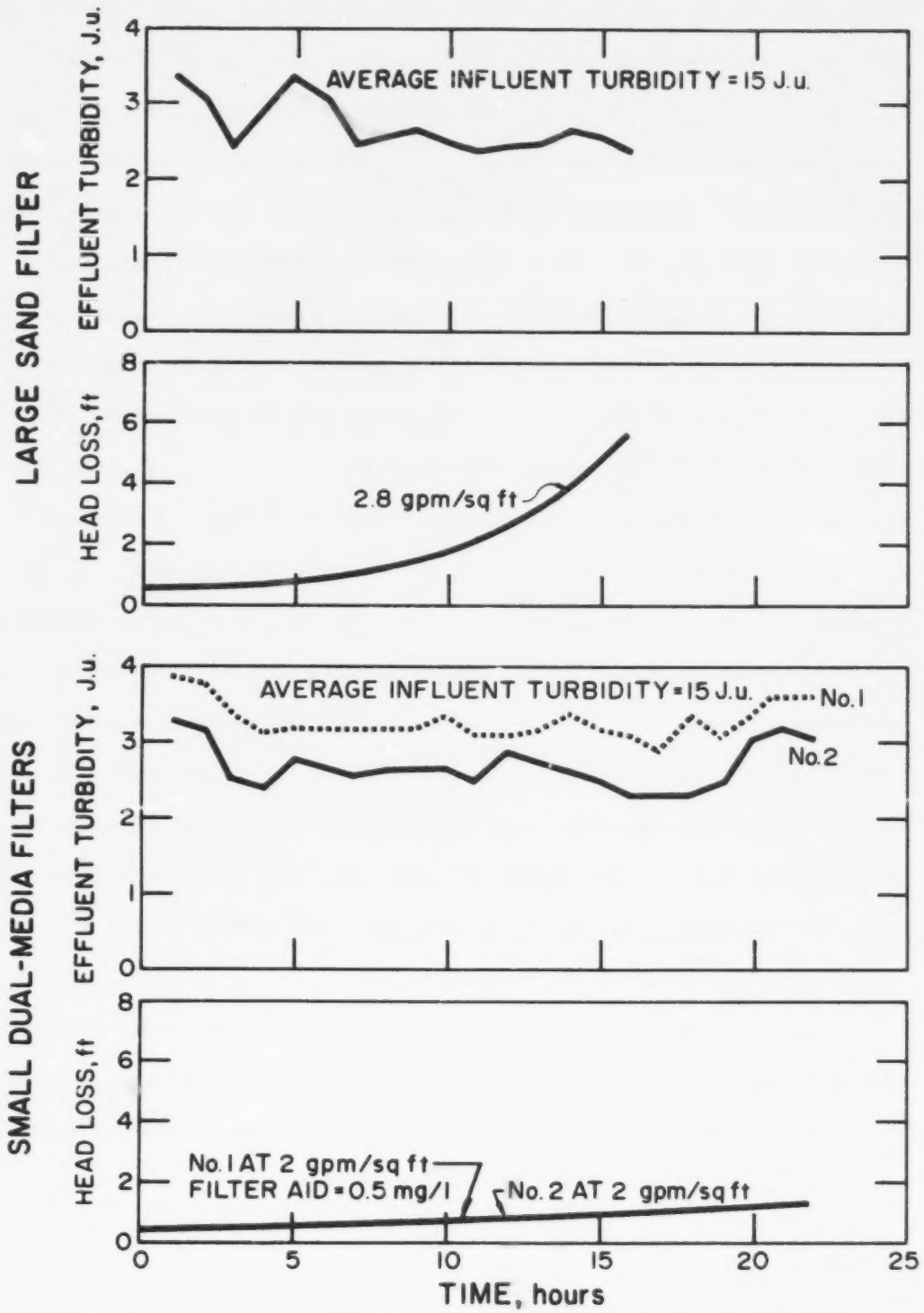

Figure 22. Head loss and turbidity values for Run 17, Oct. 1, 1963

filter aid was used showed no significant improvement in the removal of turbidity. In six runs the rate of head loss buildup for the filter that was fed the filter aid was nearly identical to the rate for the filter not fed the aid. Most of the material removed by the filter appeared to be crystalline, rather than fine floc. The total head loss curves for both the small dual-media filters and the full-scale sand filter in run 3 (Figure 5) indicate straining rather than filtration within the filter. In runs 2 and 12 (Figures 4 and 14) the head loss increased faster for the filter to which the aid had been added. Figure 15 shows the incremental head losses for both small filters during run 12. Some of the material was strengthened and thus was retained near the top of the filter. Most of the removal for filter No. 1, to which the filter aid was added, took place in the top 6 inches (head loss tap 1), whereas in filter No. 2, without filter aid, some of the material was removed by the sand (between taps 2 and 4) and by the coal (between taps 0 and 2). In run 4 (figure 6), the head loss for the small filter without filter aid increased much more rapidly in the last 12 hours of the run than that for the filter with the aid. One possible explanation might be a partial plugging of the influent line leading to filter No. 1 which might have reduced the turbidity.

Since neither changes in the filtration rate nor use of a filter aid improved effluent clarity, additional coagulant was tried. In runs 9, 11, and 14 (Figures 11, 13, and 17) 10 mg of alum per liter was added to the influent of one of the dual-media filters. The clarity of

effluent in run 9 was the only one of the three that was improved by the alum. Judged by the effluent turbidity of the small filter that was not fed alum, to produce water with a turbidity less than 1 J.u., runs 11 and 14 probably both needed either much more alum than run 9 or a further lowering of the pH before addition of the alum, or both.

Five runs (8, 10, 13, 15, and 16) were made in which another coagulant, ferric sulfate, was added to the influent of one of the small filters. Twenty-five mg/liter was added to filter No. 1 in run 8 (Figure 10) which reduced the effluent turbidity from an average of over 2 to 0.4 J.u. The run lasted 8 hours with a filtration rate of 4 gpm/sq ft. In run 10 (Figure 12) 10 mg of ferric sulfate per liter was added; this resulted in an effluent turbidity of 0.5 compared to 2.5 J.u. for the filter without the additional coagulant. The 10-hour run at 5 gpm/sq ft was terminated when the total head loss reached 8 feet. The effluent turbidity was generally kept below 1 J. u. in the remaining three runs in which 10 mg of ferric sulfate per liter was added to one of the small filters.

At the termination of run 15, the total head loss for the small filter with the ferric sulfate addition was 6.6 feet compared to 7.2 feet for the sand filter operated at a slightly lower filtration rate without additional ferric sulfate. Removal of solids throughout the coal layer as shown in Figure 19 in the filter with the additional coagulant resulted in a length of run equal to that of the sand filter, although the dual-media filter removed much more material. Filter No. 1 produced

an effluent similar to that produced by the sand filter (about 2 J.u.) but the total head loss was only 1.7 feet at termination of the run. At the termination of run 16, the small filter (No. 1) with the additional ferric sulfate and the sand filter had similar total head losses, even though the small filter was operated at 2 instead of 3 gpm/sq ft as it was in run 15. The lower filtration rate allowed the solids removal to occur in the top 6 inches of the filter (Figure 21). A higher filtration rate by the small filter would have resulted in better distribution of removal in the filter, and thus, more water produced per foot of head loss buildup.

A comparison of the small dual-media filters that had received no additional chemicals and the full-scale sand filter showed that the dual-media filter produced about three times as much water per unit surface area per run as the sand filter. This was based on the same final head loss for both filters and included filtration rates from 1 to 6 gpm/sq ft for the small filter. The small filter produced water of a quality equivalent to that of the large sand filter.

The second series of three runs was conducted during February 1964, and the results are presented in Figures 23, 24, and 25. During these runs the additional ferric sulfate was added to the total plant flow just after recarbonation. In run 18, the additional ferric sulfate dose was 20 mg/liter, and both filters produced a water with a turbidity less than 1 J.u. before a breakthrough occurred. The sand filter at 2 gpm/sq ft produced a water with a turbidity of 0.3 J.u. for 8 hours

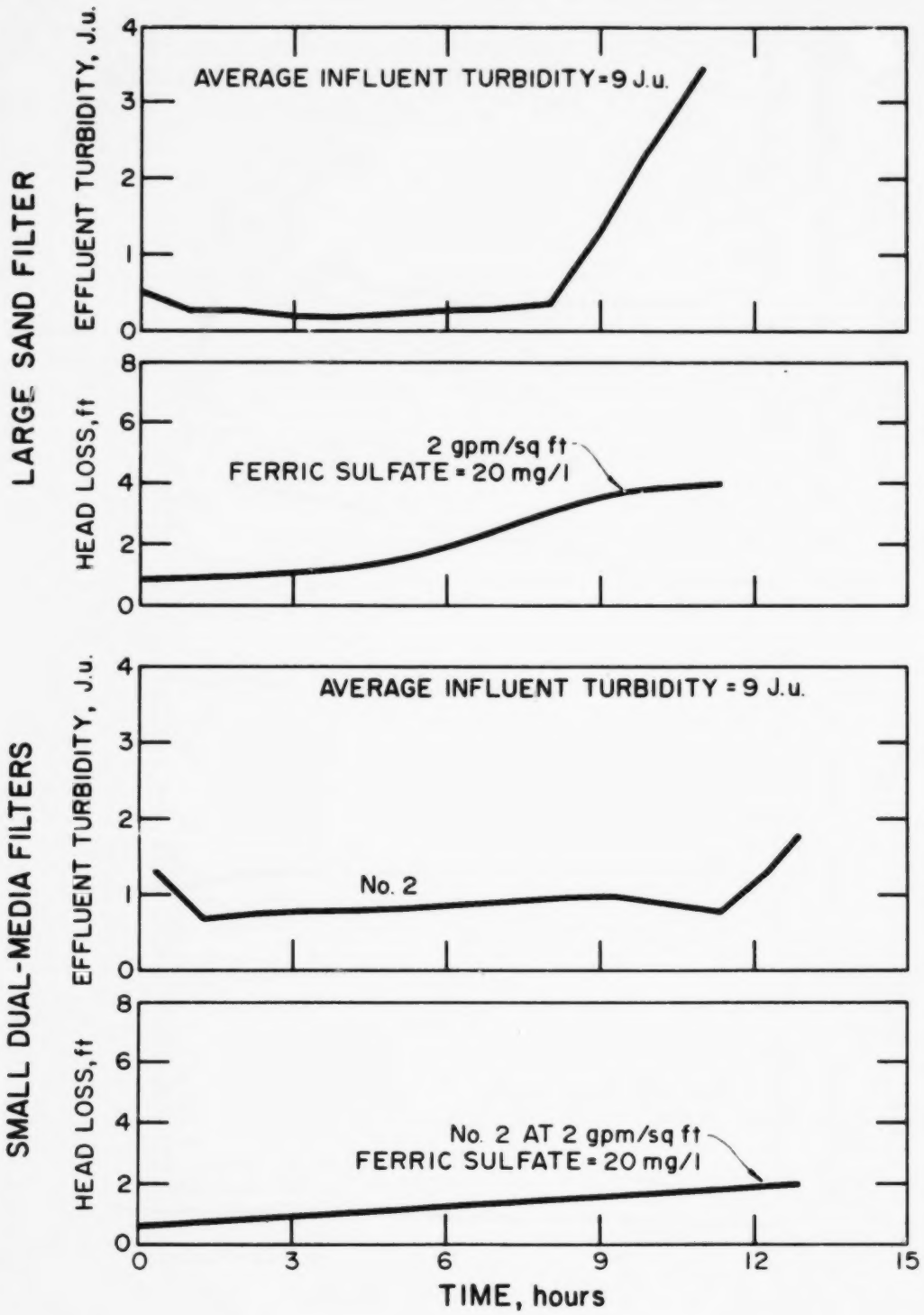

Figure 23. Head loss and turbidity values for Run 18, Feb. 27, 1964.

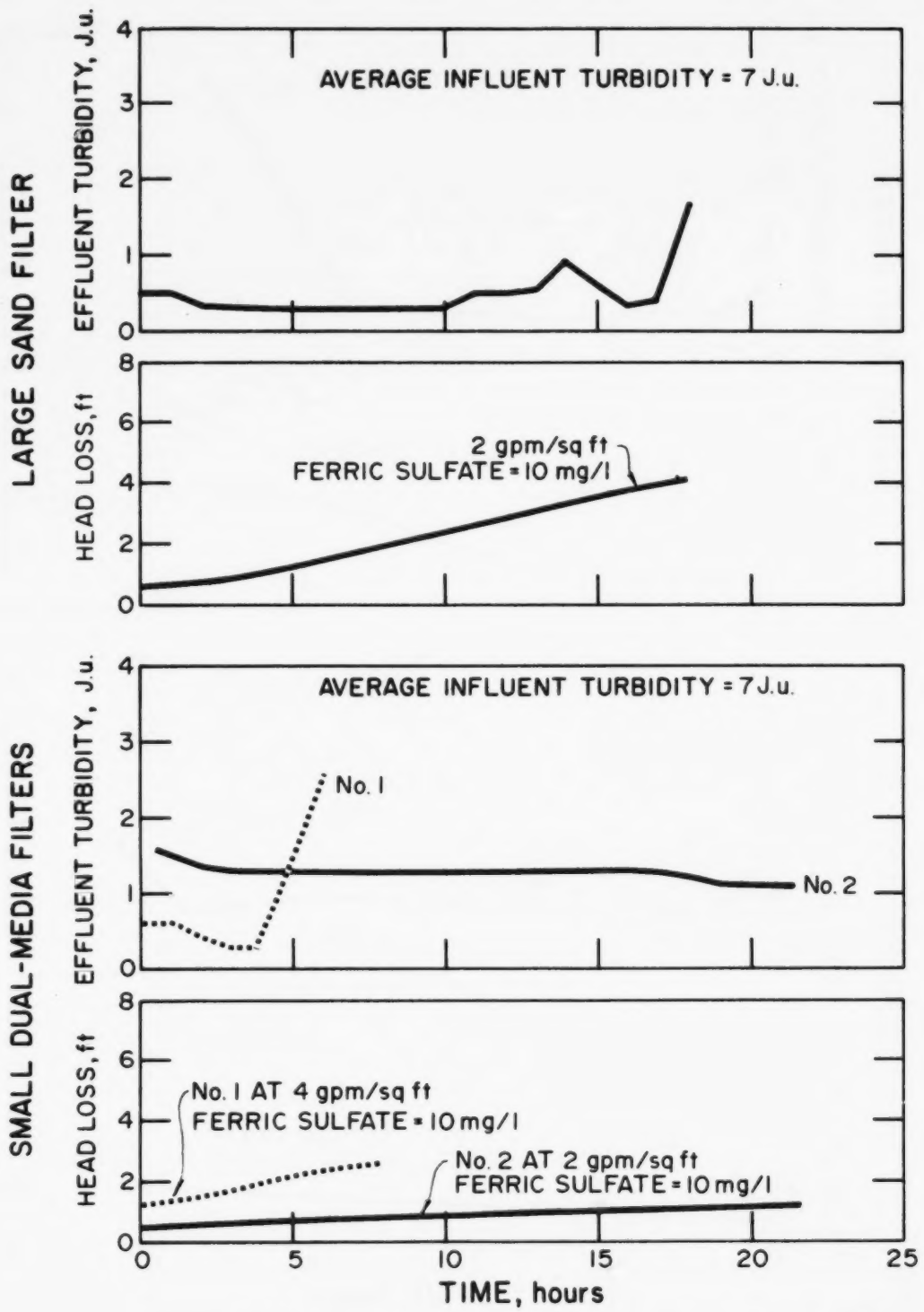

Figure 24. Head loss and turbidity values for Run 19, Feb. 27, 1964.

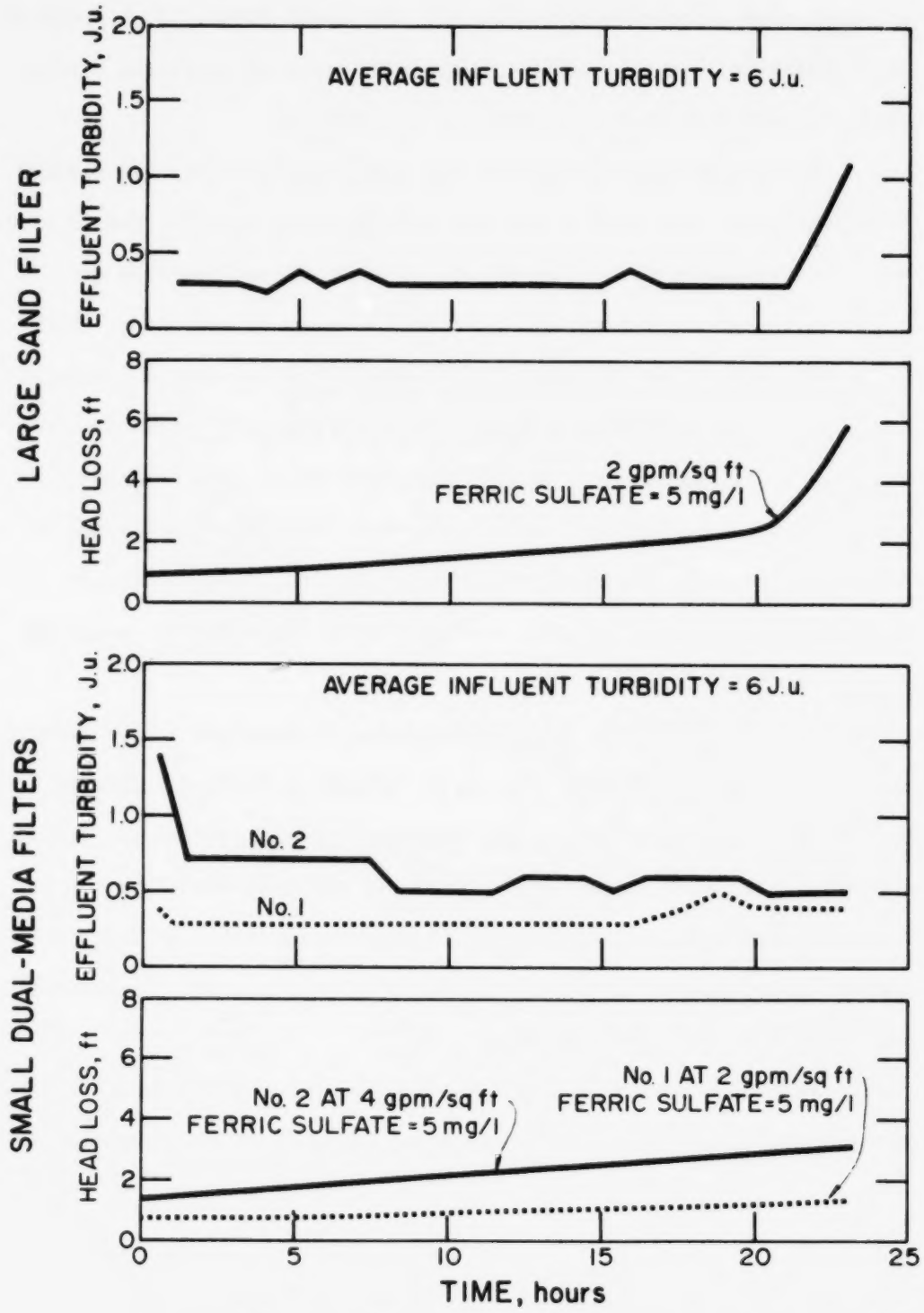

Figure 25. Head loss and turbidity values for Run 20, Feb. 28, 1964.

at which time a breakthrough occurred. The small filter, also operated at 2 gpm/sq ft, had a breakthrough after 11 hours of operation during which the effluent turbidity averaged 0.8 J.u.

Before the start of run 19, the ferric sulfate dose was reduced to 10 mg/liter. The sand filter effluent averaged 0.5 J.u. for 17 hours, and then a breakthrough occurred. No. 1 small filter operated at 4 gpm/sq ft had a breakthrough after only 4 hours of operation. Both this small filter and the sand filter should have been fed a filter aid to increase the strength of the floc that was removed. Small filter No. 2 showed a higher effluent turbidity than No. 1, but this was a result of changing the effluent rate-of-flow controller just prior to startup of the run. Experience has shown that the filter effluent turbidity is increased for several hours after replacing or repairing one of these small pumps.

Run 20 (Figure 25) was made following a reduction of the ferric sulfate dose to 5 mg/liter. All three filters produced an effluent with a turbidity less than 1 J.u.; the turbidity in small filter No. 2 effluent may still have been influenced, however, by the pump change in run 19. The rapid increase in head loss of the sand filter after 20 hours of operation was caused by an increase in the filtration rate, which may also have caused the breakthrough.

The third series of experiments consisted of three runs in March 1964, when turbidities in the Maumee River were high because

of heavy rains and the annual ice break-up. One small dual-media filter and the full-scale sand filter were used in run 21 (Figure 26). After 2 hours of operation during which both filters produced an effluent with a turbidity greater than 1 J.u., 10 mg of ferric sulfate per liter was added to the total plant flow following recarbonation. Shortly thereafter the effluent turbidities dropped to less than 1 J.u. After 22 hours of operation the full-scale sand filter had a breakthrough, and after 15 hours, the small dual-media filter operated at 4 gpm/sq ft had a breakthrough. In run 22, three filters again produced a good water until small filter No. 1 operated at 4 gpm/sq ft suffered a breakthrough. After 26 hours of operation the sand filter had a head loss of 6.8 feet, whereas filter No. 2 operated at the same filtration rate had a head loss of only 2.3 feet (Figure 27). In run 23 (Figure 28), both the sand filter operated at 4 gpm/sq ft and a small dual-media filter operated at 6 gpm/sq ft suffered breakthroughs. After 12 hours of operation, the sand filter breakthrough started; the dual-media filter, run at a higher filtration rate, lasted 9 hours.

The last series, consisting of 5 runs, was conducted during July 1964. The first run (number 24) resulted in effluent turbidities ranging from 0.2 to 1.4 J.u. (Figure 29). After 45 hours, the sand filter with a head loss of 6.5 feet was stopped; the small filter operated at 2 gpm/sq ft had a head loss, however, of only 4.0 feet after 65 hours of operation. In run 25, the water plant throughput was increased, which caused a deterioration in the effluent quality

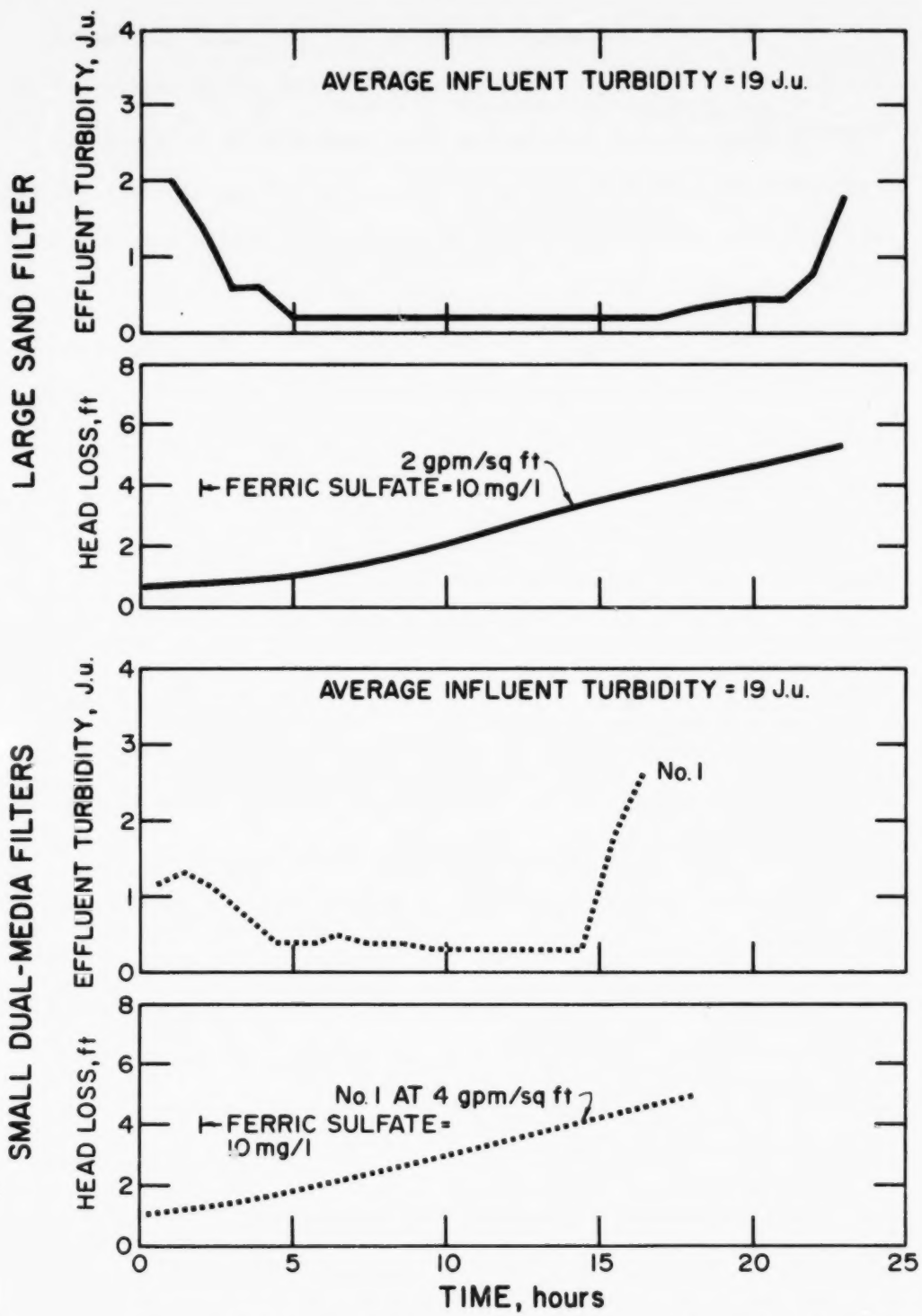

Figure 26. Head loss and turbidity values for Run 21, March 17, 1964.

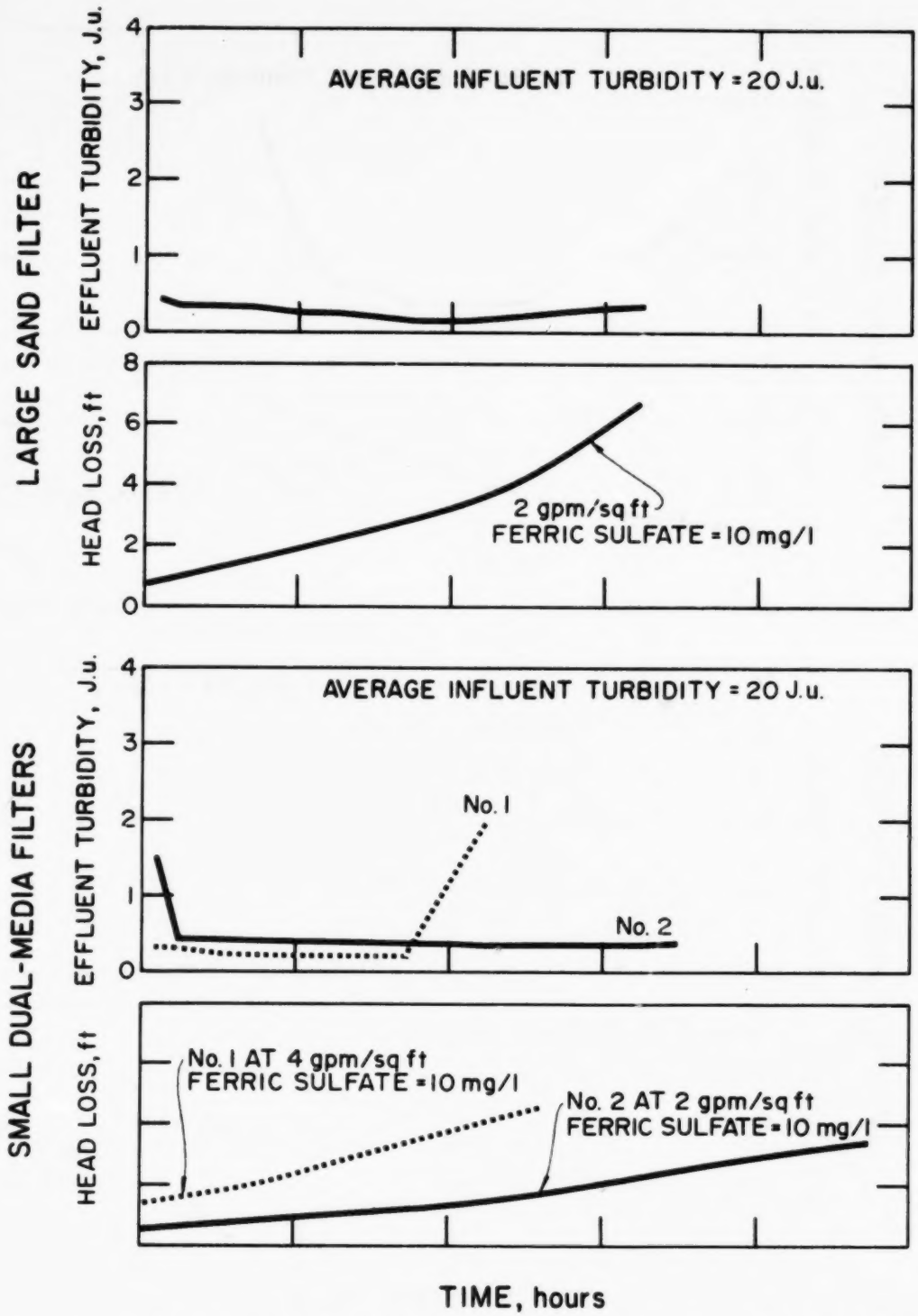

Figure 27. Head loss and turbidity values for Run 22, March 18, 1964.

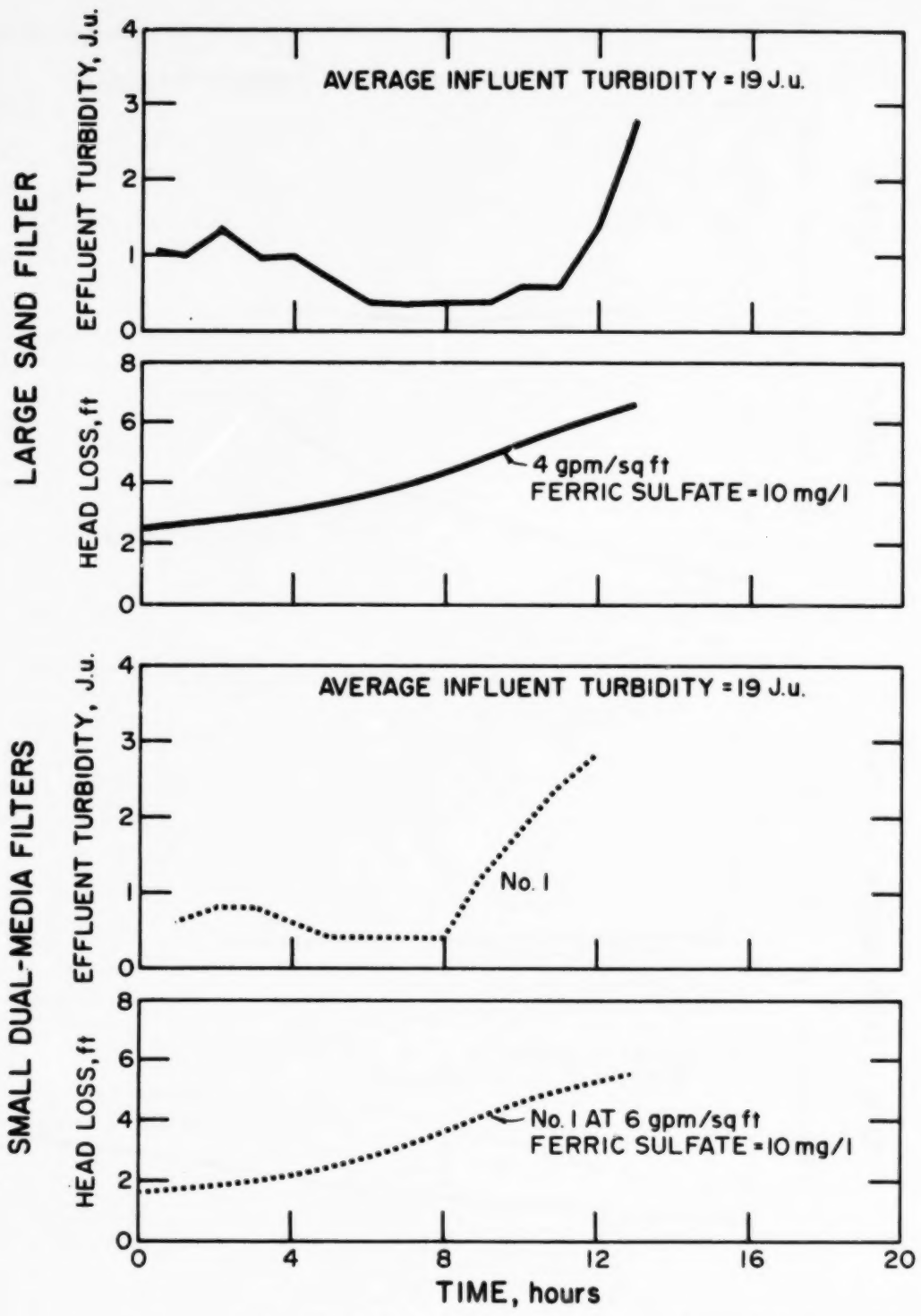

Figure 28. Head loss and turbidity values for Run 23, March 19, 1964.

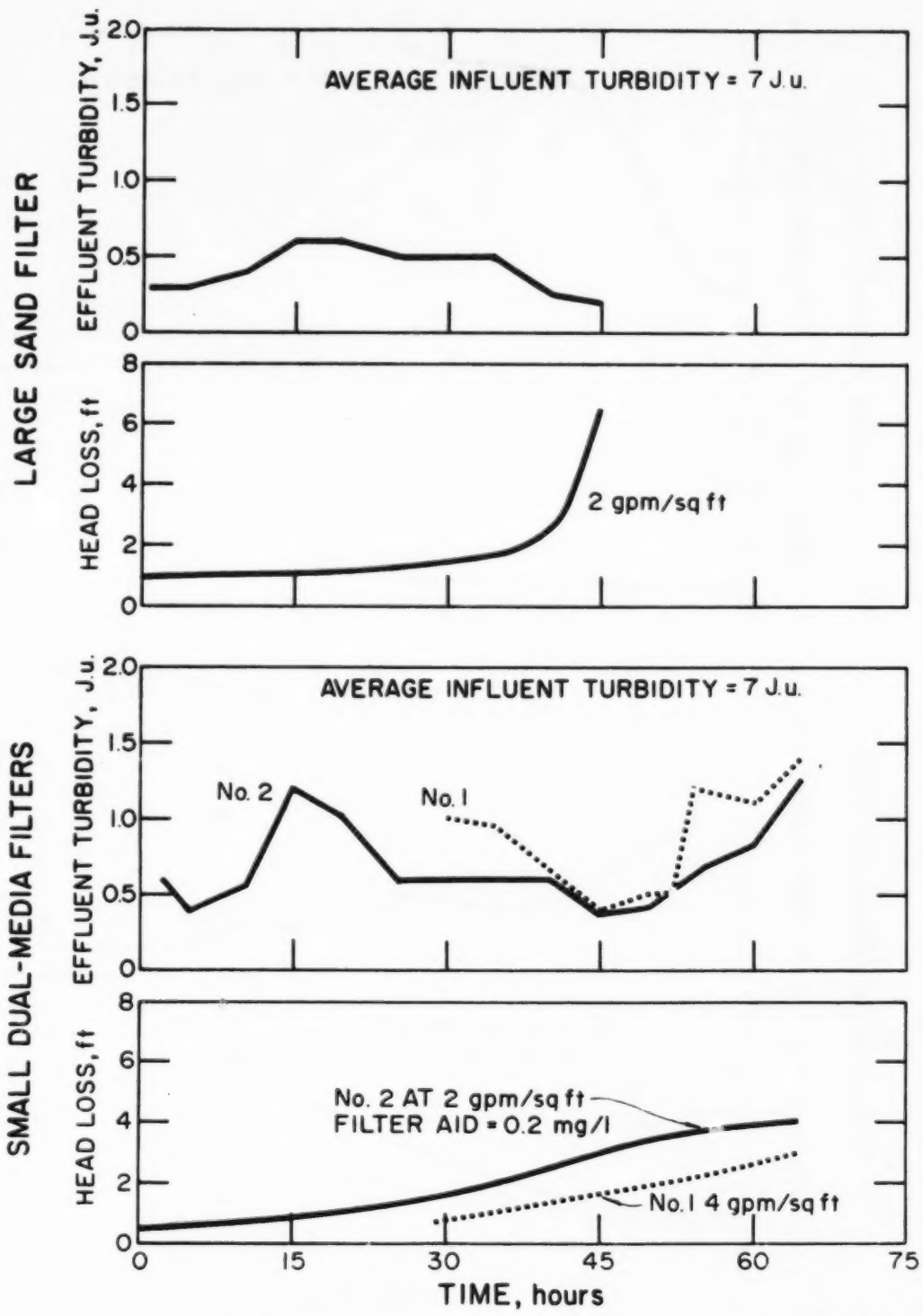

Figure 29. Head loss and turbidity values for Run 24, July 21, 1964.

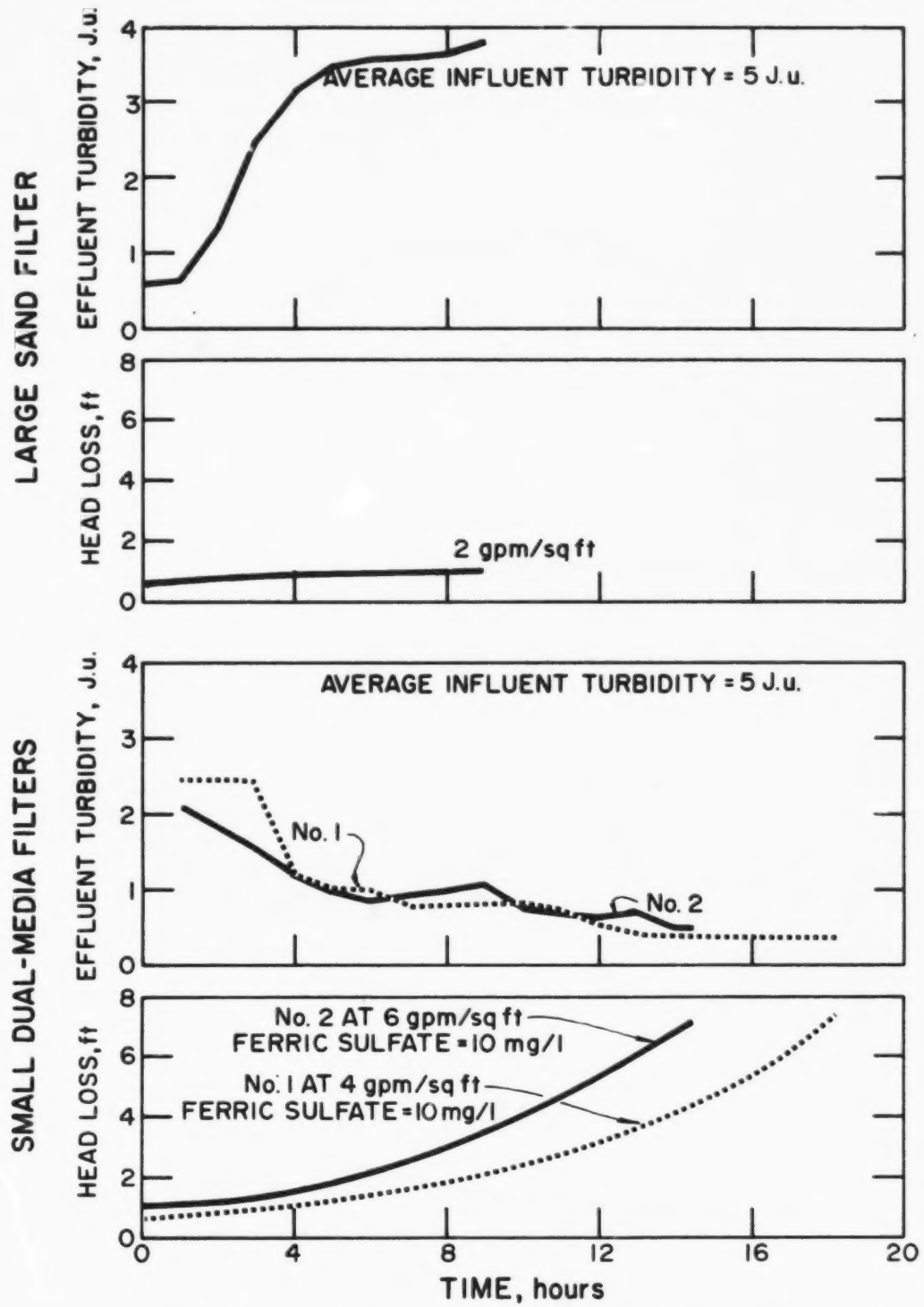

Figure 30. Head loss and turbidity values for Run 25, July 27, 1964.

from the sand filter. The quality of effluent in both small filters, which were being fed 10 mg of ferric sulfate per liter, continued to improve throughout the run. Filter No. 1 at 4 gpm/sq ft lasted 18 hours, and filter No. 2 at 6 gpm/sq ft lasted 14.5 hours.

Similar results were obtained in run 26 except that the small filter at 4 gpm/sq ft consistently produced a better water than did the filter at 6 gpm/sq ft. A slightly higher ferric sulfate dose would probably have improved the clarity of the effluent from both small filters. The following day (July 29), 20 mg of ferric sulfate per liter was added to the small filter influents and, although the filter runs were short (8.5 and 15 hours), a very good water was produced. (Figure 32).

In the last run, number 28, with the addition of 15 mg of ferric sulfate per liter, both small filters produced a water with a turbidity less than 0.4 J.u., and the sand filter without the additional coagulant produced a water with a turbidity greater than 1.0 J.u.

Algae

Several sets of grab samples were preserved and shipped to the Cincinnati Laboratory for algae identification and enumeration. A summary of this information is presented in Table 6. In nearly every case the predominant organism was the diatom Cyclotella;e.g., of 36,000 organisms found in the raw water on November 19, 1963, 31,000 were identified as Cyclotella, and on December 17, 1963 39,000 of 54,000 were listed as Cyclotella.

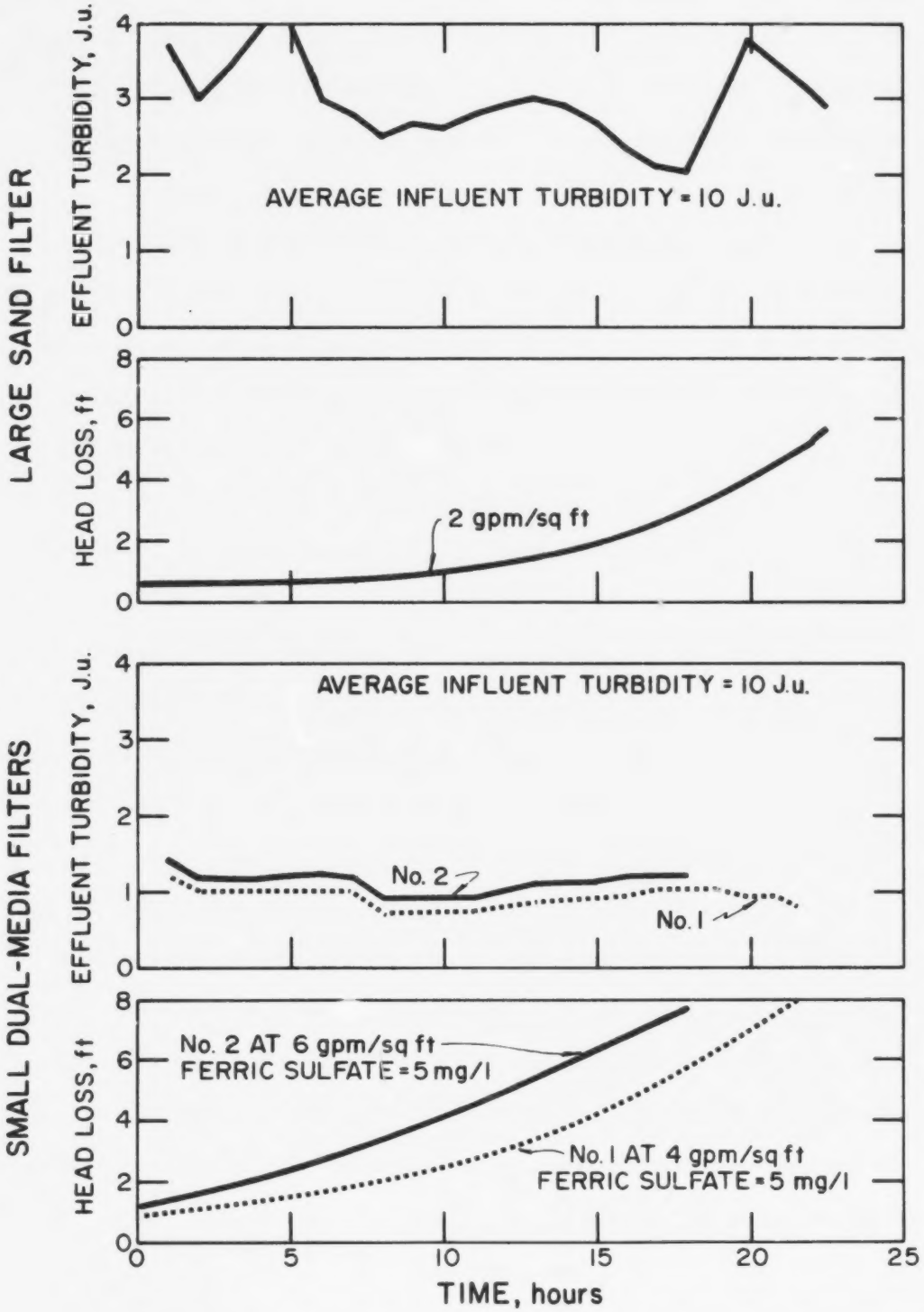

Figure 31. Head loss and turbidity values for Run 26, July 28, 1964.

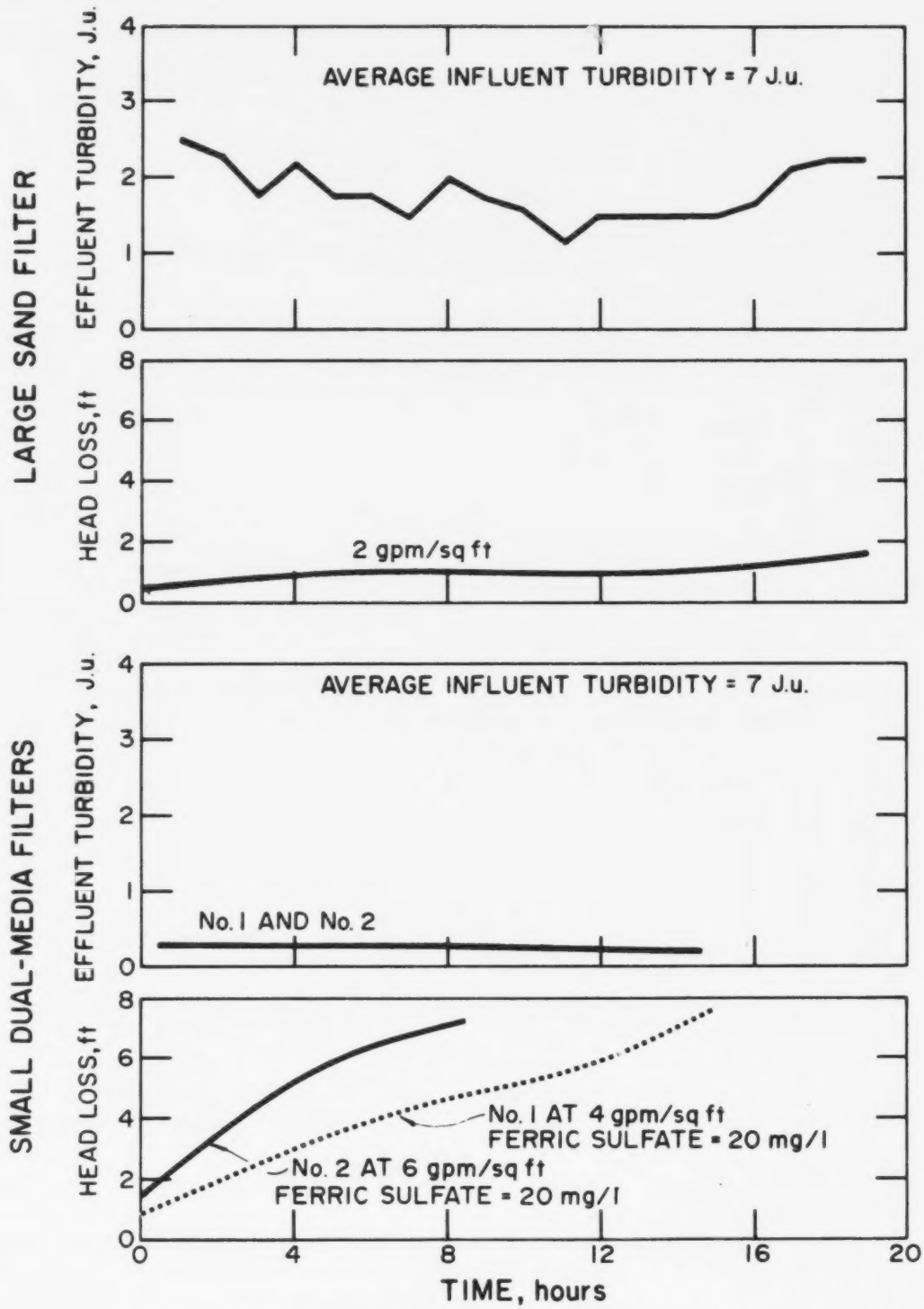
LARGE SAND FILTER
EFFLUENT TURBIDITY, J.u.
AVERAGE INFLUENT TURBIDITY = 7 J.u.
HEAD LOSS, ft
2 gpm/sq ft
SMALL DUAL-MEDIA FILTERS
EFFLUENT TURBIDITY, J.u.
AVERAGE INFLUENT TURBIDITY = 7 J.u.
No. 1 AND No. 2
HEAD LOSS, ft
No. 1 AT 4 gpm/sq ft
FERRIC SULFATE = 20 mg/l
No. 2 AT 6 gpm/sq ft
FERRIC SULFATE = 20 mg/l
TIME, hours

Figure 32. Head loss and turbidity values for Run 27, July 29, 1964.

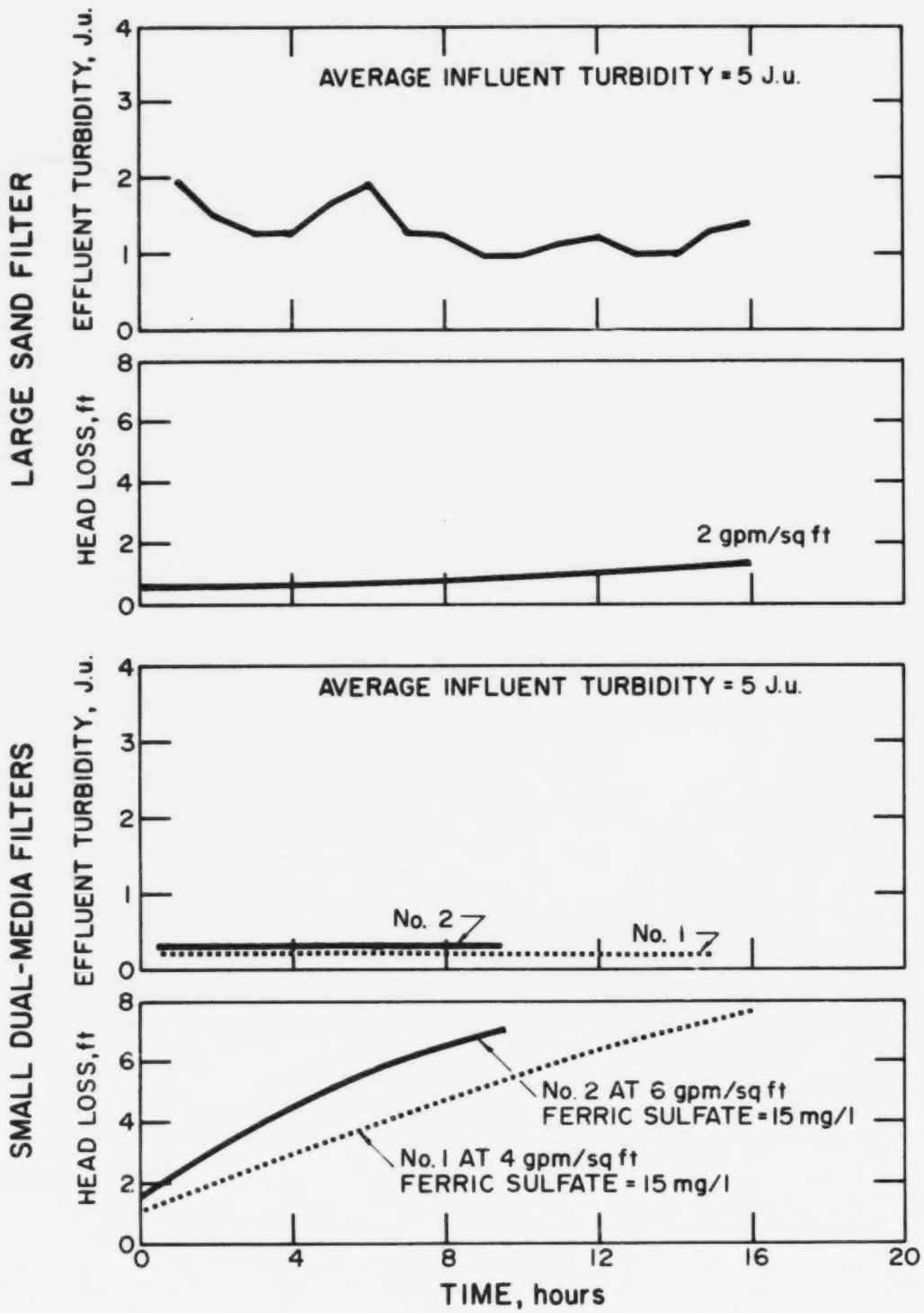

Figure 33. Head loss and turbidity values for Run 28, July 30, 1964.

TABLE 6. SUMMARY OF ALGAE DATA

	Raw Water		Filter influent		Sand effluent		Dual-media effluent	
Date	Algae no/ml	Turbidity J.u.	Algae no/ml	Turbidity J.u.	Algae no/ml	Turbidity J.u.	Algae no/ml	Turbidity J.u.
11/19/63	36,000	--	620	--	--	--	54	--
12/17/63	54,000	40	--	--	--	--	--	--
1/23/64	8,600	40	170	2.5	36	0.6	--	--
1/30/64	3,900	--	1,100	--	270	--	380	--
2/7/64	860	50	210	45	63	2.4	90	1.7
2/28/64	2,000	21	110	11	39	0.3	13	0.4
3/20/64	650	150	<12	22	<12	0.3	<12	0.4
4/3/64	340	90	24	19	<12	3.0	<12	--
5/25/64	11,000	97	12	5	24	0.9	--	--

Most of the samples were taken during special runs, rather than during the 28 runs discussed earlier. Not enough samples were taken to evaluate removal differences due to media type or filtration rate. Inasmuch as the algae load entering the filters was generally lower than anticipated, no extensive sampling was initiated. The limited data available indicated that the better the turbidity removal, the better the algae removal. The influence of algae load on length of filter run could not be determined because of insufficient data.

Particle Size Distribution

Several sets of samples taken for algae identification were also used to evaluate particle size distributions, shown in Figures 34 through 39. These distributions were obtained by passing a sample of water through a 6-channel Coulter Counter. The raw-water samples were allowed to settle for 60 minutes to remove the large particles and thus eliminate plugging of the measuring device. As expected, maintaining the floc size during transit was difficult despite the use of preservatives and shaking before testing. Nevertheless, an idea of the number and size of particles present in the sample was obtained.

All filter-effluent samples tested had more than 10,000 particles per milliliter with diameters greater than 1 micron, and in every case the raw water had more than 100,000 particles per milliliter whose diameters were greater than 2 microns. As expected, the larger the particles in the filter influent, the higher the percentage of removal.

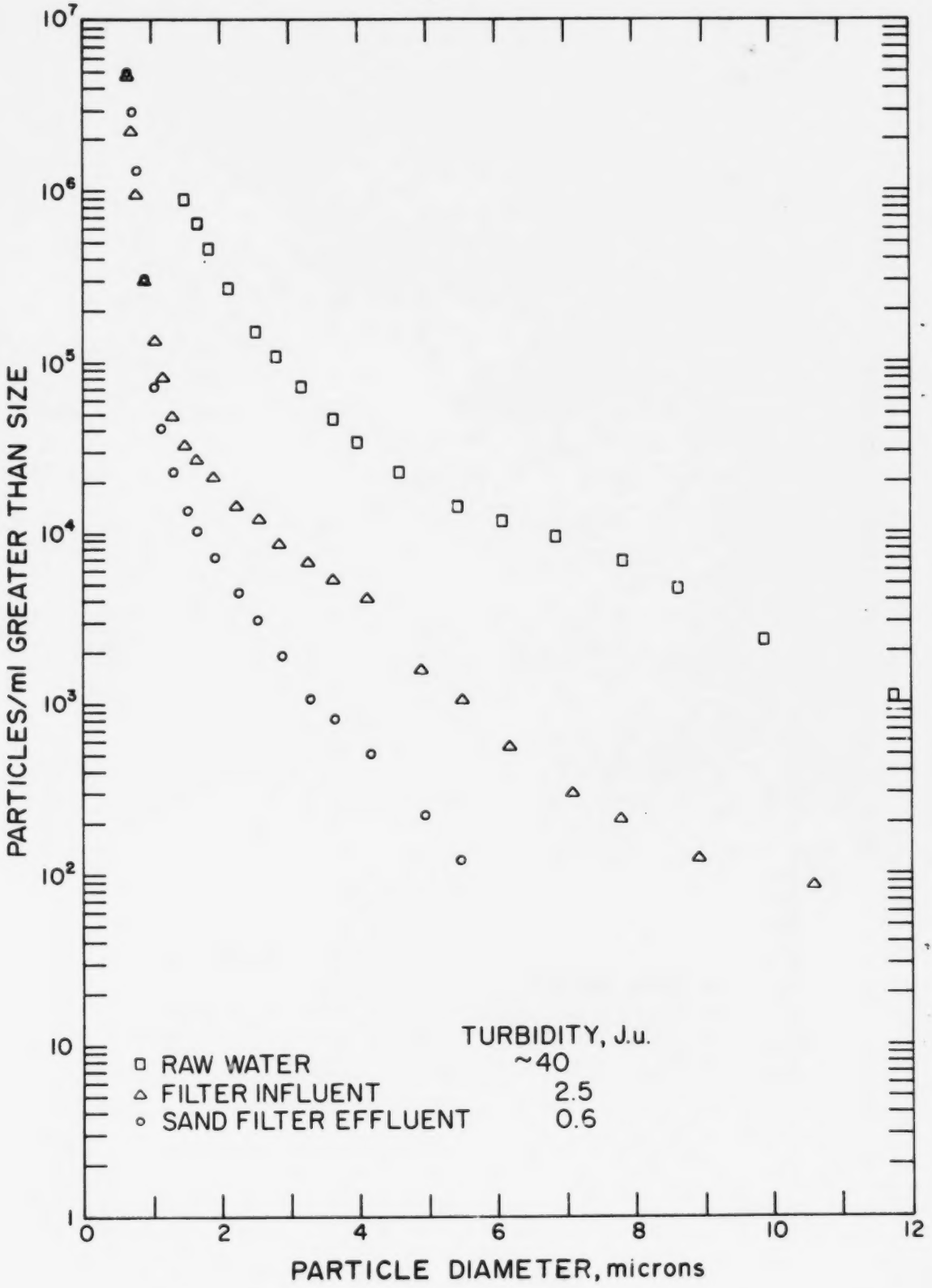

Figure 34. Particle size distribution, Jan. 23, 1964.

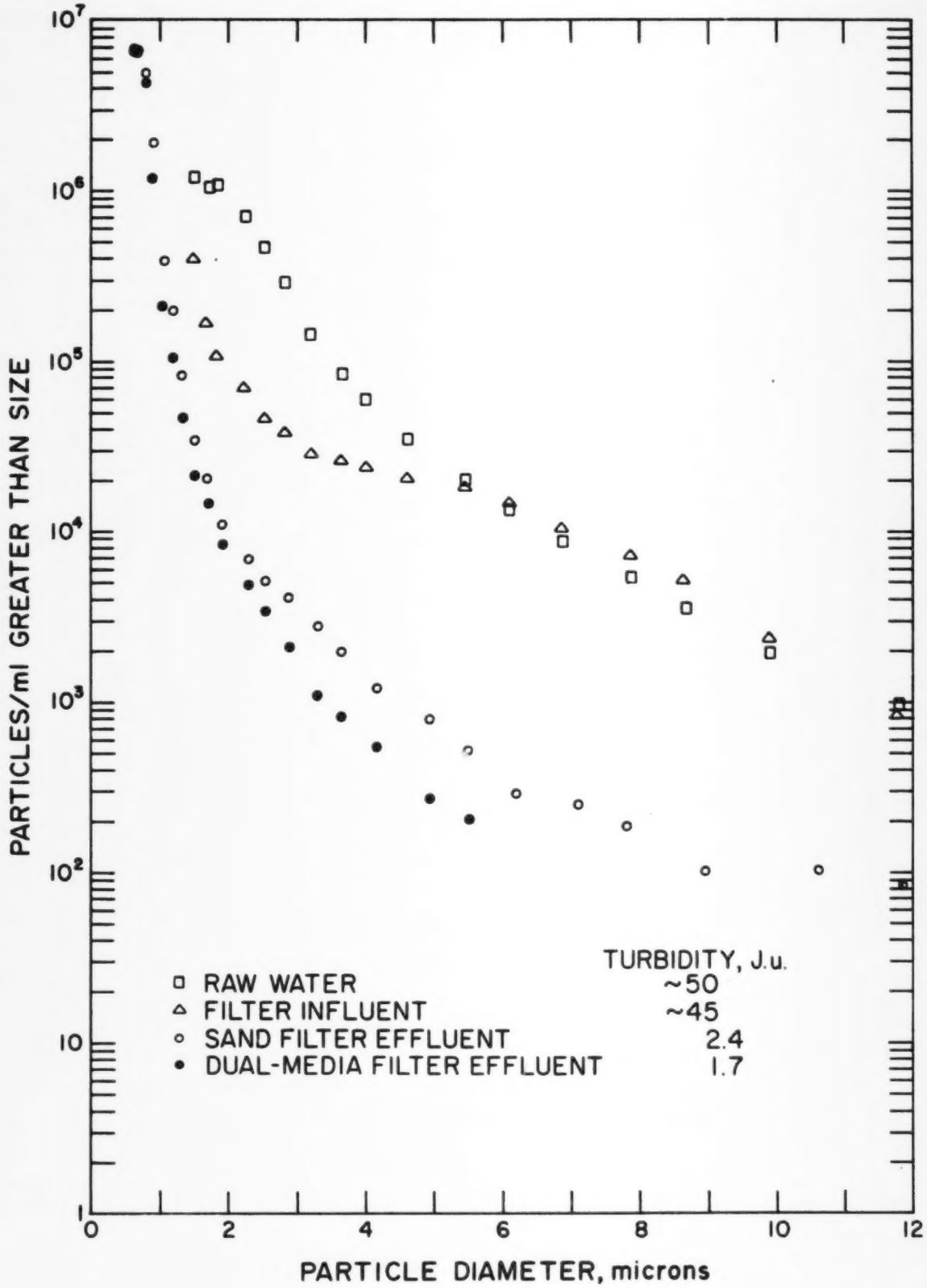

Figure 35. Particle size distribution, Feb. 7, 1964

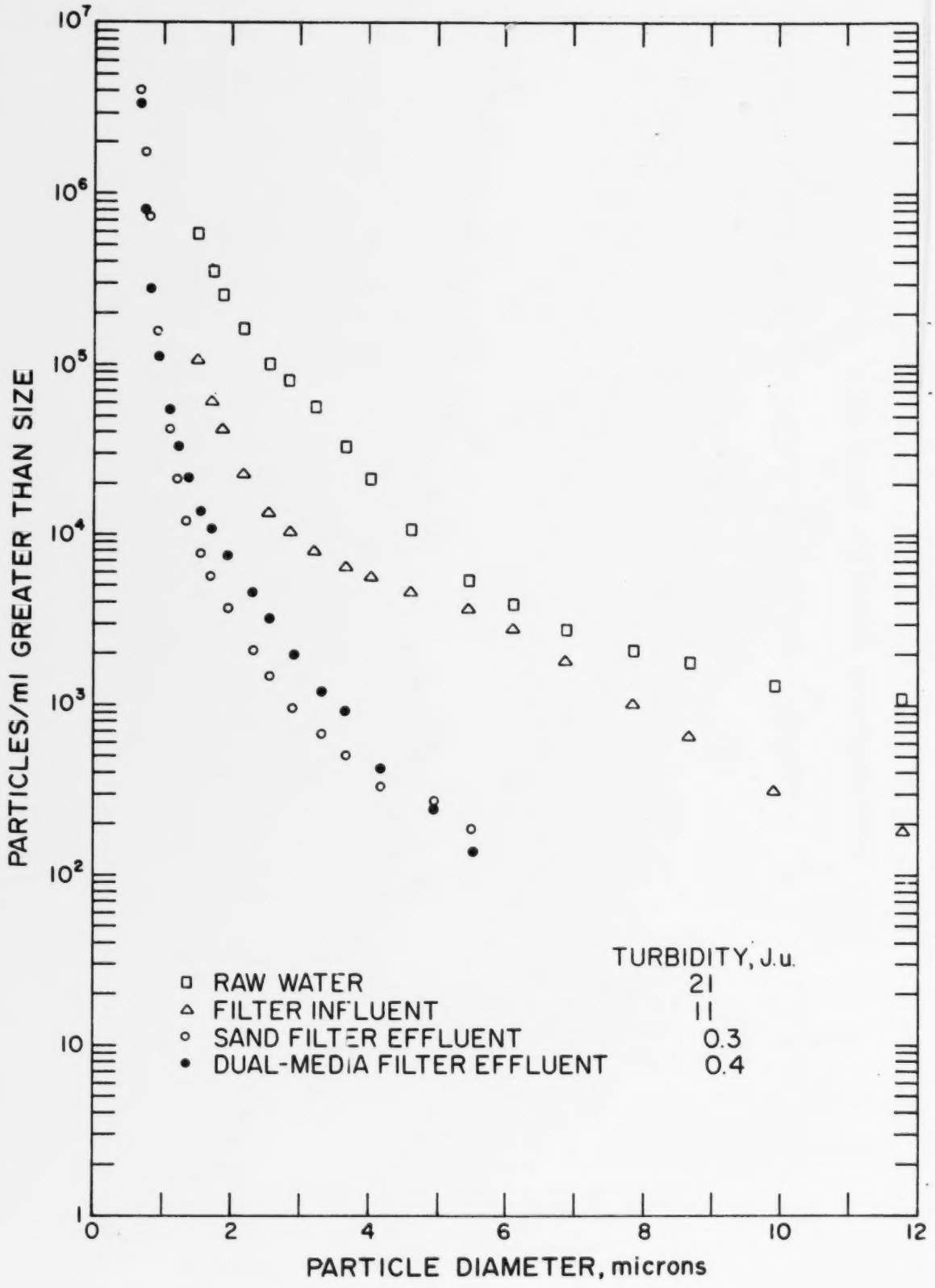

Figure 36. Particle size distribution, Feb. 28, 1964.

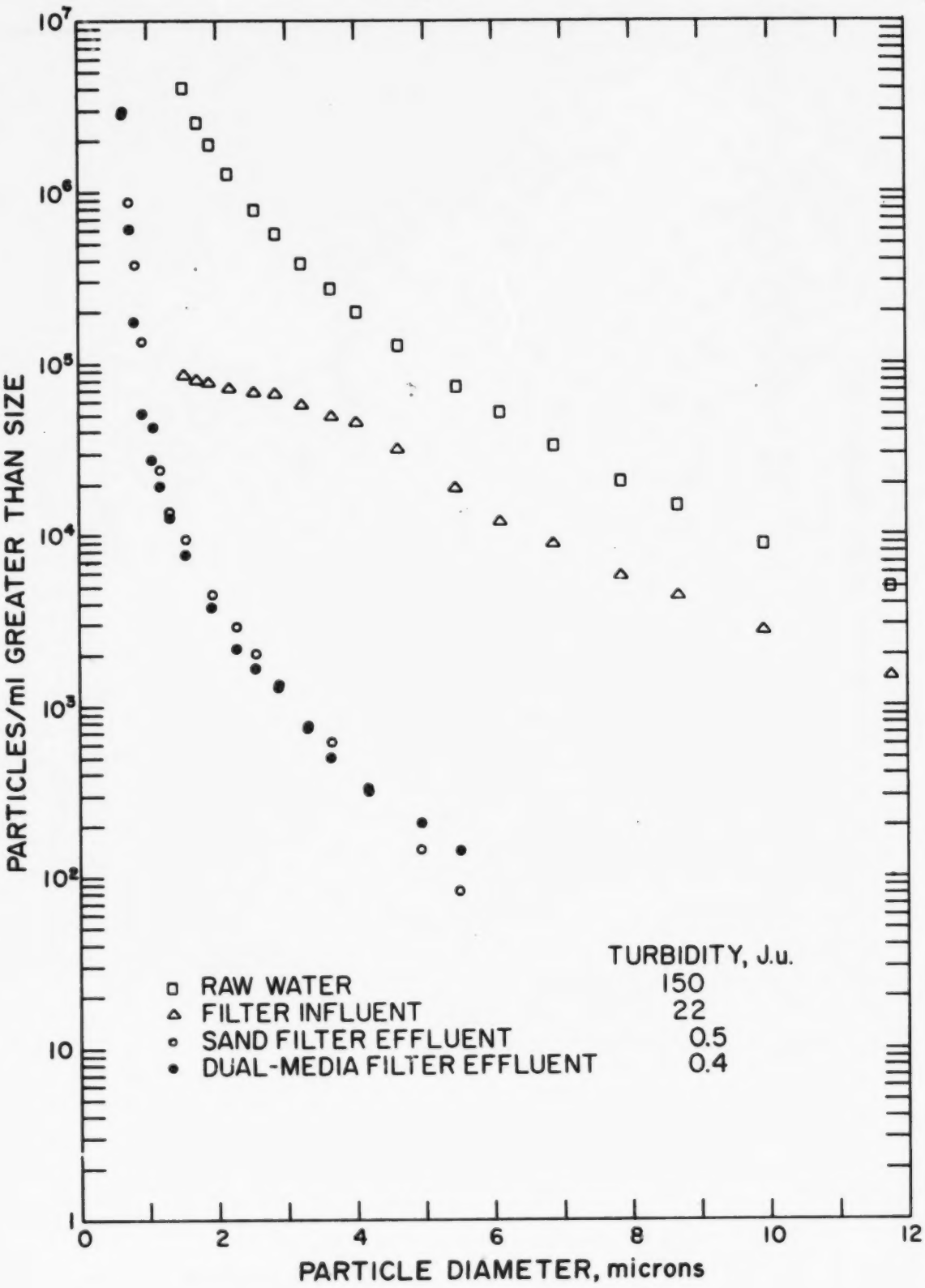

Figure 37. Particle size Distribution, March 20, 1964.

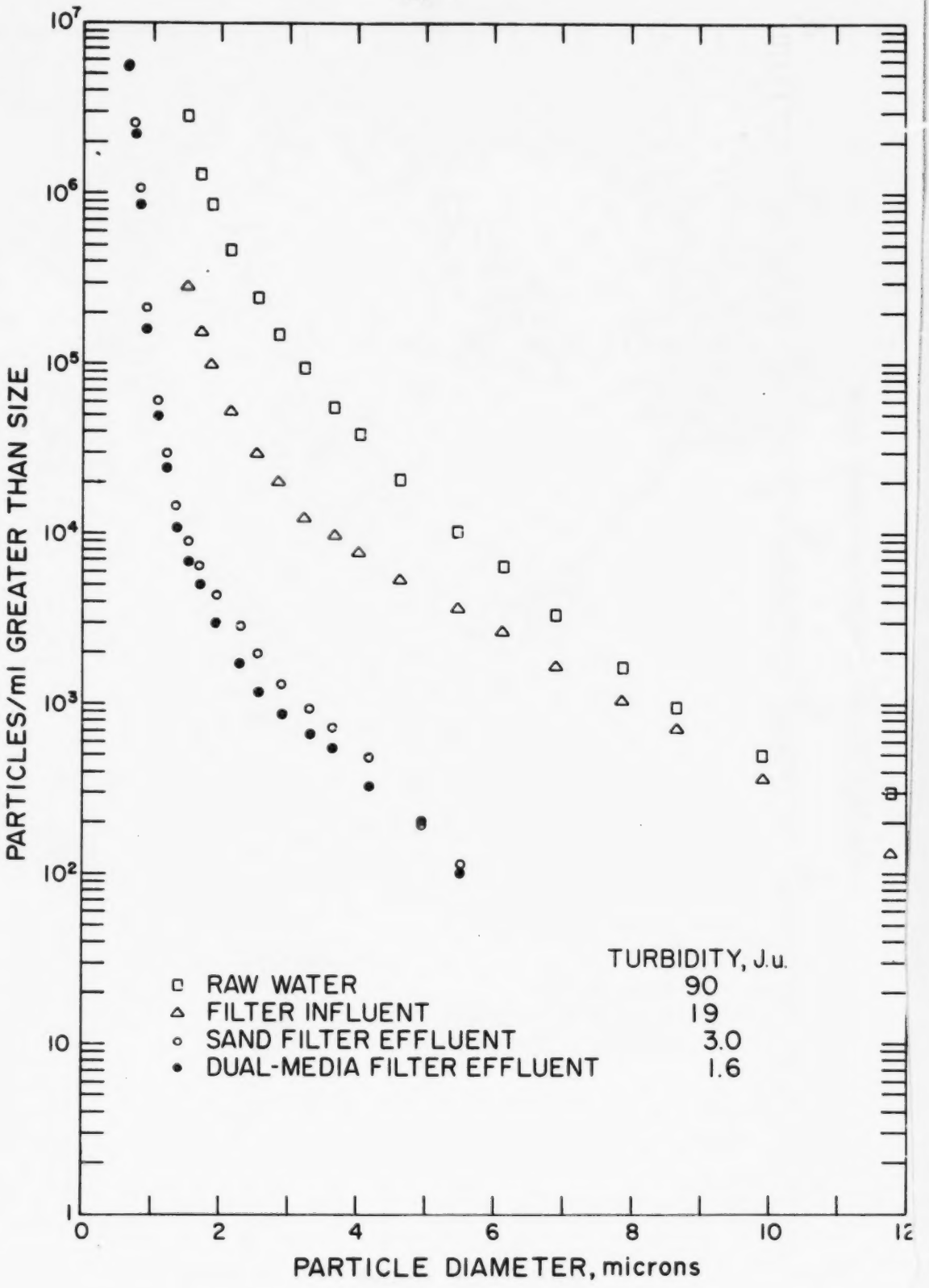

Figure 38. Particle size distribution, April 3, 1964.

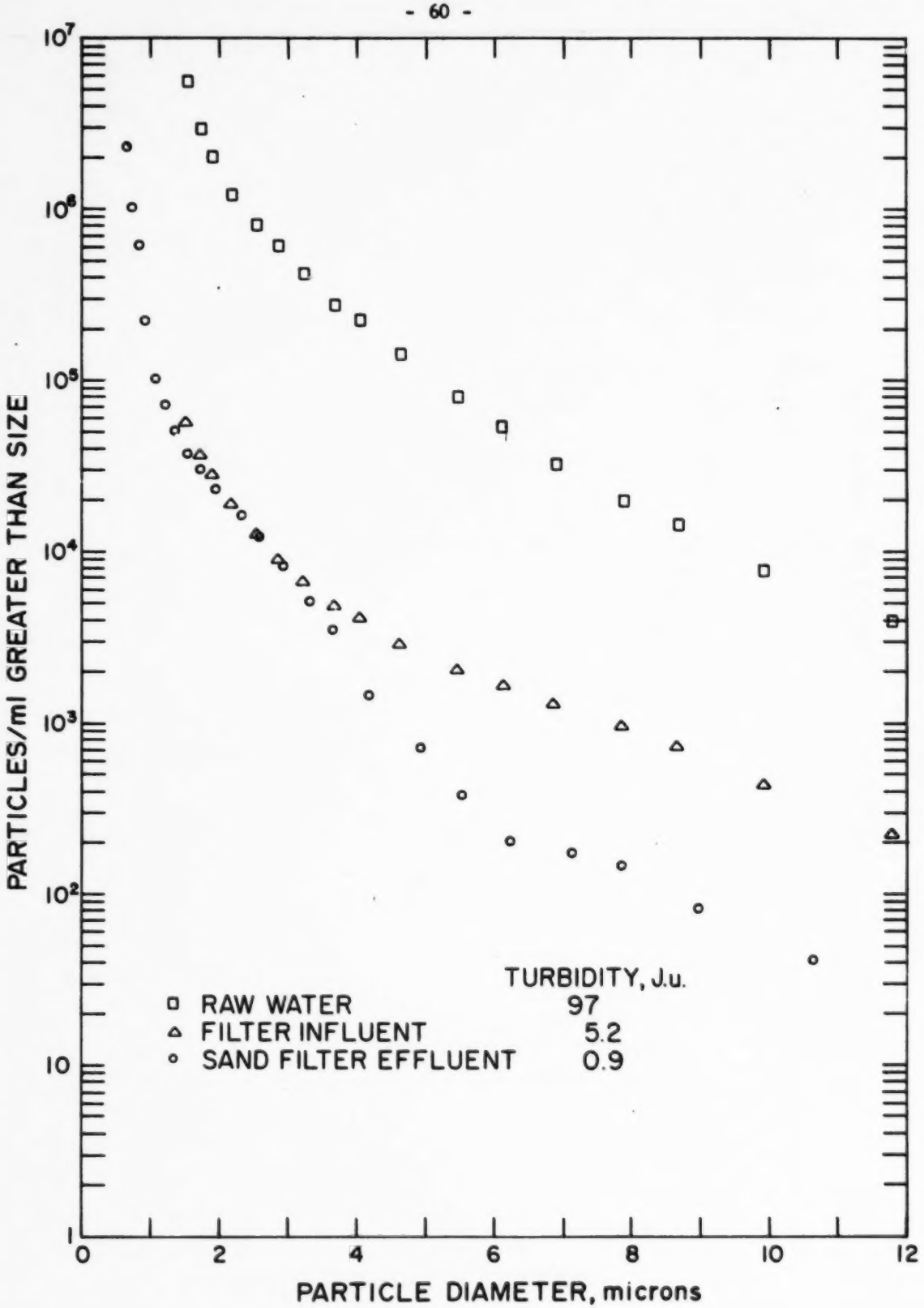

Figure 39. Particle size Distribution, May 25, 1964.

Particle numbers increase very rapidly as particle diameters get below 1 micron.

DISCUSSION

Continuous measurement of the turbidity of the filter effluent from small dual-media filters and a full-scale sand filter as well as the incremental head-loss measurements revealed several interesting considerations. Effluent quality was not degraded significantly due to either variations in filtration rate from 1 to 6 gpm/sq ft or alterations in filter media. Both types of filters produced water of high turbidity regardless of filtration rate during certain periods such as when the water plant operated above design capacity and when the plant operated near design capacity during the winter months. At these times more material was carried out of the up-flow clarifiers and this, in combination with the limited recarbonation facilities, resulted in a carry-over to the filters of fine crystalline material that was difficult to remove without additional coagulant. Total head-loss curves during these runs apparently were the result of straining rather than filtration within the bed. The larger crystalline material was evidently strained out with the finer material passing through the filter. Although the dual-media filter produced water of no lower turbidity than that of the sand filter, it did produce three times as much water per unit area per foot of final head loss as the sand filter.

One ray to reduce the amount of material passed by the filter was to add ferric sulfate to the filter influent. The amount required

depended on the amount and type of material in the filter influent and the desired clarity of the effluent stream. Throughout the test period, including all investigations, the required dose of ferric sulfate to produce an effluent with a turbidity less than 0.5 J.u. ranged from 2 to 25 mg/liter. That the same result could have been accomplished by feeding additional ferric sulfate to the clarifier influent is doubtful inasmuch as post-precipitation due to inadequate recarbonation probably created the problems encountered in filtration. In the runs where ferric sulfate was added to the influent of both the large and small filters, the small dual-media filter produced over 2.5 times as much water of similar quality per unit area per foot of final head loss as did the sand filter.

In the few runs in which alum was added to a small filter influent, very little improvement was noted. Inasmuch as the pH was generally 8.5 or over and no attempt was made to adjust the pH prior to addition of the alum, conditions were less than optimum for its use. Some improvement due to alum addition was shown in run 9. During this run the water plant was operating at less than the design flow, which resulted in a situation less critical as far as the clarifiers and recarbonation units were concerned. This is shown by the fact that a better water was produced by the sand filter. The alum floc was of some benefit probably because the recarbonation was more complete and thus the pH was lower than it was in the other runs in which alum was tried.

The use of 0.05 to 1.0 mg of a filter aid per liter to improve the effluent clarity during troublesome periods proved of little or no benefit with this type of crystalline material that was not removed by the filter. Although the filter aid was not added along with the ferric sulfate in the runs in which a breakthrough occurred, judged from past experience[4], a small amount would have delayed or eliminated the breakthroughs.

CONCLUSIONS

1. Filtration rates from 1 to 6 gpm/sq ft had very little influence on the turbidity of the filter effluent.

2. The dual-media filter produced a water comparable in quality to that produced by the full-scale sand filter, but the amount of water produced by the dual-media filter was about three times that produced by the sand filter.

3. The addition to the filter influent of 0.05 to 1.0 mg of a polyelectrolyte per liter accomplished very little under the conditions encountered.

4. Alum as a coagulant added to the filter influent was not very beneficial at the application rate and pH levels indicated.

5. A higher quality effluent can be produced during troublesome periods by addition of some ferric sulfate to the water just prior to filtration. The required concentration depends on the amount and type of material present in the water.

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